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**WORKS OF
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RAILROAD CONSTRUCTION.

THEORY AND PRACTICE.

*A TEXT-BOOK FOR THE USE OF STUDENTS IN
COLLEGES AND TECHNICAL SCHOOLS.*

BY

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etc.*

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PREFACE.

THE preparation of this book was begun several years ago, when much of the subject-matter treated was not to be found in print, or was scattered through many books and pamphlets, and was hence unavailable for student use. Portions of the book have already been printed by the mimeograph process or have been used as lecture-notes, and hence have been subjected to the refining process of classroom use.

The author would call special attention to the following features:

a. Transition curves; the multiform-compound-curve method is used, which has been followed by many railroads in this country; the particular curves here developed have the great advantage of being exceedingly simple, and although the method is not theoretically exact, it is demonstrable that the differences are so small that they may safely be neglected.

b. A system of earthwork computations by means of a slide-rule (which accompanies the volume) which enables one to compute readily the volume of the most complicated earthwork forms with an accuracy only limited by the precision of the cross-sectioning.

c. The "mass curve" in earthwork; the theory and use of this very valuable process.

d. Tables I, II, III, and IV have been computed *ab novo*. Tables I and II were checked (after computation) with other tables, which are generally considered as standard, and all discrepancies were further examined. They are believed to be perfect.

e. Tables V, VI, VII, and IX have been borrowed, by permission, from "Ludlow's Mathematical Tables." It is believed that five-place tables give as accurate results as actual field practice requires. Tables VIII and X have been compiled to conform with Ludlow's system.

The author wishes to acknowledge his indebtedness to Mr. Chas. A. Sims, civil engineer and railroad contractor, for reading and revising the portions relating to the cost of earthwork.

Since the book is written primarily for students of railroad engineering in technical institutions, the author has assumed the usual previous preparation in algebra, geometry, and trigonometry.

WALTER LORING WEBB.

UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA,
Jan. 1, 1900.

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RAILROAD CONSTRUCTION.

CHAPTER I.

RAILROAD SURVEYS.

THE proper conduct of railroad surveys presupposes an adequate knowledge of almost the whole subject of railroad engineering, and particularly of some of the complicated questions of Railroad Economics, which are not generally studied except at the latter part of a course in railroad engineering, if at all. This chapter will therefore be chiefly devoted to methods of instrumental work, and the problem of choosing a general route will be considered only as it is influenced by the topography or by the application of those elementary principles of Railroad Economics which are self-evident or which may be accepted by the student until he has had an opportunity of studying those principles in detail.

RECONNOISSANCE SURVEYS.

1. **Character of a reconnoissance survey.** A reconnoissance survey is a very hasty examination of a belt of country to determine which of all possible or suggested routes is the most promising and best worthy of a more detailed survey. It is essentially very rough and rapid. It aims to discover those salient features which instantly stamp one route as distinctly superior to another and so narrow the choice to routes which are so nearly equal in value that a more detailed survey is necessary to decide between them.

2. Selection of a general route. The general question of running a railroad between two towns is usually a financial rather than an engineering question. Financial considerations usually determine that a road *must* pass through certain more or less important towns between its termini. When a railroad runs through a thickly settled and very flat country, where, from a topographical standpoint, the road may be run by any desired route, the "right-of-way agent" sometimes has a greater influence in locating the road than the engineer. But such modifications of alignment, on account of business considerations, are foreign to the engineer's side of the subject, and it will be hereafter assumed that topography alone determines the location of the line. The consideration of those larger questions combining finance and engineering (such as passing by a town on account of the necessary introduction of heavy grades in order to reach it) is likewise ignored.

3. Valley route. This is perhaps the simplest problem. If the two towns to be connected lie in the same valley, it is frequently only necessary to run a line which shall have a nearly uniform grade. The reconnoissance problem consists largely in determining the difference of elevation of the two termini of this division and the approximate horizontal distance so that the proper grade may be chosen. If there is a large river running through the valley, the road will probably remain on one side or the other throughout the whole distance, and both banks should be examined by the reconnoissance party to determine which is preferable. If the river may be easily bridged, both banks may be alternately used, especially when better alignment is thereby secured. A river valley has usually a steeper slope in the upper part than in the lower part. A uniform grade throughout the valley will therefore require that the road climbs up the side slopes in the lower part of the valley. In case the "ruling grade" * for the whole road is as great as or greater

* The *ruling grade* may here be loosely defined as the maximum grade which is permissible. This definition is not strictly true, as may be seen later when studying Railroad Economics, but it may here serve the purpose.

than the steepest natural valley slope, more freedom may be used in adopting that alignment which has the least cost—regardless of grade. The natural slope of large rivers is almost invariably so low that grade has no influence in determining the choice of location. When bridging is necessary, the river banks should be examined for suitable locations for abutments and piers. If the soil is soft and treacherous much difficulty may be experienced and the choice of route may be largely determined by the difficulty of bridging the river except at certain favorable places.

4. Cross-country route. A cross-country route always has one or more summits to be crossed. The problem becomes more complex on account of the greater number of possible solutions and the difficulty of properly weighing the advantages and disadvantages of each. The general aim should be to choose the lowest summits and the highest stream crossings, provided that by so doing the grades between these determining points shall be as low as possible and shall not be greater than the ruling grade of the road. Nearly all railroads combine cross-country and valley routes to some extent. Usually the steepest natural slopes are to be found on the cross-country routes, and also the greatest difficulty in securing a low through grade. An approximate determination of the ruling grade is usually made during the reconnoissance. If the ruling grade has been previously decided on by other considerations, the leading feature of the reconnoissance survey will be the determination of a general route along which it will be possible to survey a line whose maximum grade shall not exceed the ruling grade.

5. Mountain route. The streams of a mountainous region frequently have a slope exceeding the desired ruling grade. In such cases there is no possibility of securing the desired grade by following the streams. The penetration of such a region may only be accomplished by “development”—accompanied perhaps by tunneling. “Development” consists in deliberately increasing the length of the road between two extremes of elevation so that the rate of grade shall be as low as desired.

The usual method of accomplishing this is to take advantage of some convenient formation of the ground to introduce some lateral deviation. The methods may be somewhat classified as follows:

(a) Running the line up a convenient lateral valley, turning a sharp curve and working back up the opposite slope. As shown in Fig. 1, the considerable rise between *A* and *B* was

FIG. 1.

surmounted by starting off in a very different direction from the general direction of the road; then, when about one-half of the desired rise had been obtained, the line crossed the valley and continued the climb along the opposite slope. (b) *Switchback*. On the steep side-hill *BCD* (Fig. 1) a very considerable gain in elevation was accomplished by the switchback *CD*. The gain in elevation from *B* to *D* is very great. On the other hand, the speed must always be slow; there are two complete stoppages of the train for each run; all trains must run backward from *C* to *D*. (c) *Bridge spiral*. When a valley is so narrow at some point that a bridge or viaduct of reasonable length can span the valley at a considerable elevation above the bottom of the valley, a bridge spiral may be desirable. In

Fig. 2 the line ascends the stream valley past *A*, crosses the stream at *B*, works back to the narrow place at *C*, and there crosses itself, having gained perhaps 100 feet in elevation. (d) *Tunnel spiral*. This is the reverse of the previous plan.



FIG. 2.

FIG. 3

It implies a thin steep ridge, so thin at some place that a tunnel through it will not be excessively long. Switchbacks and spirals are sometimes necessary in mountainous countries, but they should not be considered as normal types of construction. A region must be very difficult if these devices cannot be avoided.

Rack railways and cable roads, although types of mountain railroad construction, will not be here considered.

6. Existing maps. The maps of the U. S. Geological Survey are exceedingly valuable as far as they have been completed. So far as topographical considerations are concerned, they almost dispense with the necessity for the reconnoissance and "first preliminary" surveys. Some of the State Survey maps will give practically the same information. County and township maps can often be used for considerable information as to the relative *horizontal* position of governing points, and even some

approximate data regarding elevations may be obtained by a study of the streams. Of course such information will not dispense with surveys, but will assist in so planning them as to obtain the best information with the least work. When the relative horizontal positions of points are reliably indicated on a map, the reconnoissance may be reduced to the determination of the relative elevations of the governing points of the route.

7. Determination of relative elevations. A recent description of European methods includes spirit-leveling in the reconnoissance work. This may be due to the fact that, as indicated above, previous topographical surveys have rendered unnecessary the "exploratory" survey which is required in a new country, and that their reconnoissance really corresponds more nearly to our preliminary.

The perfection to which barometrical methods have been brought has rendered it possible to determine differences of elevation with sufficient accuracy for reconnoissance purposes by the combined use of a mercurial and an aneroid barometer. The mercurial barometer should be kept at "headquarters," and readings should be taken on it at such frequent intervals that any fluctuation is noted, and throughout the period that observations with the aneroid are taken in the field. At each observation there should also be recorded the time, the reading of the attached thermometer, and the temperature of the external air. For uniformity, the mercurial readings should then be "reduced to 32° F." Before starting out, a reading of the aneroid should be taken at headquarters coincident with a reading of the mercurial. The difference is one value of the correction to the aneroid. As soon as the aneroid is brought back another comparison of readings should be made. Even though there has been considerable rise or fall of pressure in the interval, the *difference* in readings (the correction) should be substantially the same provided the aneroid is a good instrument. The best aneroids read directly to $\frac{1}{100}$ of an inch of mercury and may be estimated to $\frac{1}{1000}$ of an inch—which corresponds to about 0.9 foot difference of elevation. In the field there should be read,

at each point whose elevation is desired, the aneroid, the time, and the temperature. These readings, corrected by the mean value of the correction between the aneroid and the mercurial, should then be combined with the reading of the mercurial (interpolated if necessary) for the times of the aneroid observations and the difference of elevation obtained. [See the author's "Problems in the Use and Adjustment of Engineering Instruments," Prob. 22.] Important points should be observed more than once if possible. Such duplicate observations will be found to give surprisingly concordant results even when a general fluctuation of atmospheric pressure so modifies the tabulated readings that an agreement is not at first apparent. Variations of pressure produced by high winds, thunder-storms, etc., will generally vitiate possible accuracy by this method. By "headquarters" is meant any place whose elevation above any given datum is known and where the mercurial may be placed and observed while observations within a range of several miles are made with the aneroid. If necessary the elevation of a new headquarters may be determined by the above method, but there should be if possible several independent observations whose accordancy will give a fair idea of their accuracy.

The above method should be neither slighted nor used for more than it is worth. When properly used, the errors are compensating rather than cumulative. When used, for example, to determine that a pass *B* is 260 feet higher than a determined bridge crossing at *A* which is six miles distant, and that another pass *C* is 310 feet higher than *A* and is ten miles distant, the figures, even with all necessary allowances for inaccuracy, will give an engineer a good idea as to the choice of route especially as affected by ruling grade. There is no comparison between the time and labor involved in obtaining the above information by barometric and by spirit-leveling methods, and *for reconnaissance purposes* the added accuracy of the spirit-leveling method is hardly worth its cost.

8. Horizontal measurements, bearings, etc. When there is no map which may be depended on, or when only a skeleton

map is obtainable, a rapid survey, sufficiently accurate for the purpose, may be made by using a pocket compass for bearings and a telemeter, odometer, or pedometer for distances. The telemeter [stadia] is more accurate, but it requires a definite clear sight from station to station, which may be difficult through a wooded country. The odometer, which records the revolutions of a wheel of known circumference, may be used even in rough and wooded country, and the results may be depended on to a small percentage. The pedometer (or pace-measurer) depends for its accuracy on the actual movement of the mechanism for each pace and on the uniformity of the pacing. Its results are necessarily rough and approximate, but it may be used to fill in some intermediate points in a large skeleton map. A hand-level is also useful in determining the relative elevation of various topographical features which may have some bearing on the proper location of the road.

9. Importance of a good reconnoissance. The foregoing instruments and methods should be considered only as aids in exercising an educated common sense, without which a proper location cannot be made. The reconnoissance survey should command the best talent and the greatest experience available. If the general route is properly chosen, a comparatively low order of engineering skill can fill in a location which will prove a paying railroad property; but if the general route is so chosen that the ruling grades are high and the business obtained is small and subject to competition, no amount of perfection in detailed alignment or roadbed construction can make the road a profitable investment.

PRELIMINARY SURVEYS.

10. Character of survey. A preliminary railroad survey is properly a topographical survey of a belt of country which has been selected during the reconnoissance and within which it is estimated that the located line will lie. The width of this belt will depend on the character of the country. When a railroad

is to follow a river having very steep banks the choice of location is sometimes limited at places to a very few feet of width and the belt to be surveyed may be correspondingly narrowed. In very flat country the desired width may be only limited by the ability to survey points with sufficient accuracy at a considerable distance from what may be called the "backbone line" of the survey.

11. Cross-section method. This is the only feasible method in a wooded country, and is employed by many for all kinds of country. The *backbone* line is surveyed either by observing magnetic bearings with a compass or by carrying forward

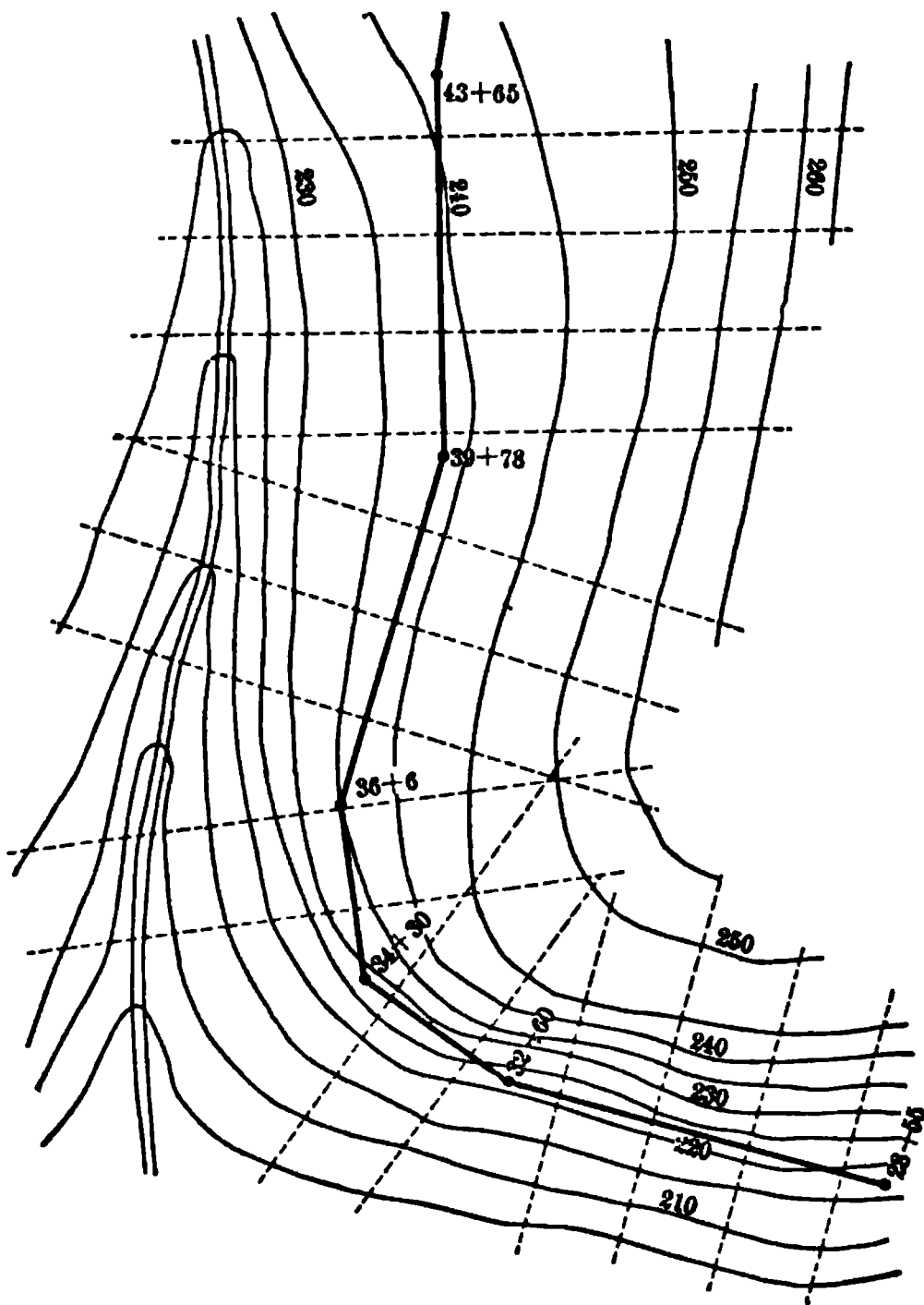


FIG. 4.

absolute azimuths with a transit. The compass method has the disadvantages of limited accuracy and the possibility of

considerable local error owing to local attraction. On the other hand there are the advantages of greater simplicity, no necessity for a back rodman, and the fact that the errors are purely local and not cumulative, and may be so limited, with care, that they will cause no vital error in the subsequent location survey. The transit method is essentially more accurate, but is liable to be more laborious and troublesome. If a large tree is encountered, either it must be cut down or a troublesome operation of offsetting must be used. If the compass is employed under these circumstances, it need only be set up on the far side of the tree and the former bearing produced. An error in reading a transit azimuth will be carried on throughout the survey. An error of only five minutes of arc will cause an offset of nearly eight feet in a mile. Large azimuth errors may, however, be avoided by immediately checking each new azimuth with a needle reading. It is advisable to obtain true azimuth at the beginning of the survey by an observation on the sun or Polaris, and to check the azimuths every few miles by azimuth observations. Distances along the backbone line should be measured with a chain or steel tape and stakes set every 100 feet. When a course ends at a substation, as is usually the case, the remaining portion of the 100 feet should be measured along the next course. The level party should immediately obtain the elevations (to the nearest tenth of a foot) of all stations, and also of the lowest points of all streams crossed and even of dry gullies which would require culverts.

12. Cross-sectioning. It is usually desirable to obtain contours at five-foot intervals. This may readily be done by the use of a Locke level (which should be held on top of a simple five-foot stick), a tape, and a rod ten feet in length graduated to feet and tenths. The method of use may perhaps be best explained by an example. Let Fig. 5 represent a section *perpendicular* to the survey line—such a section as would be made by the dotted lines in Fig. 4. *C* represents the station point. Its elevation as determined by the level is, say, 158.3 above datum. When the Locke level on its five-foot rod is placed at

C, the level has an elevation of 163.3. Therefore when a point is found (as at *a*) where the level will read 3.3 on the rod, that

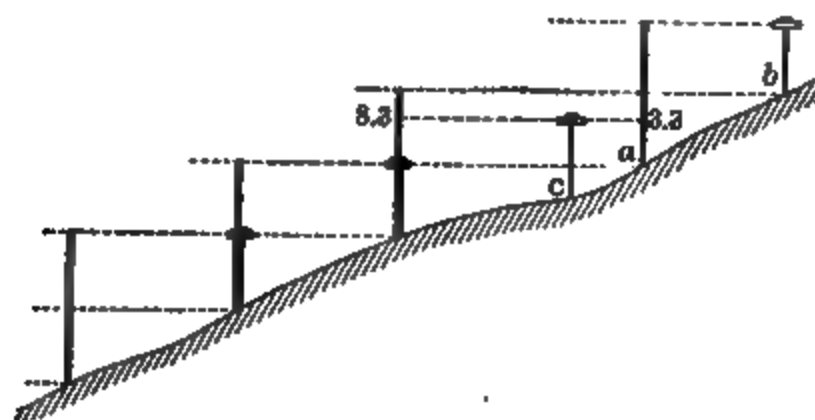


FIG. 5.

point has an elevation of 160.0 and its distance from the center gives the position of the 160-foot contour. Leaving the long rod at that point (*a*), carry the level to some point (*b*) such that the level will sight at the *top* of the rod. *b* is then on the 165-

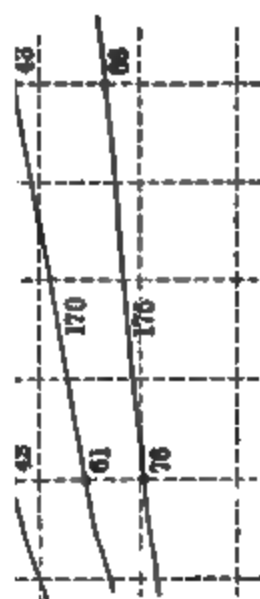


FIG. 6.

foot contour, and the *horizontal* distance *ab* added to the horizontal distance *ac* gives the position of that contour from the center. The contours on the lower side are found similarly. The first rod reading will be 8.3, giving the 155-foot contour. Plot the results in a note-book which is ruled in quarter-inch squares, using a scale of 100 feet per inch in both directions.

Plot the work up the page; then when looking ahead along the line, the work is properly oriented. When a contour crosses the survey line, the place of crossing may be similarly determined. If the ground flattens out so that five-foot contours are very far apart, the absolute elevations of points at even fifty-foot distances from the center should be determined. The method is exceedingly rapid. Whatever error or inaccuracy occurs is confined in its effect to the one station where it occurs. The work being thus plotted in the field, unusually irregular topography may be plotted with greater certainty and no great error can occur without detection. It would even be possible by this method to detect a gross error that might have been made by the level party.

13. Stadia method. This method is best adapted to fairly open country where a "shot" to any desired point may be taken without clearing. The *backbone* survey line is the same as in the previous method except that each course is limited to the practicable length of a stadia sight. The distance between stations should be checked by foresight and backsight—also the vertical angle. Azimuths should be checked by the needle. Considering the vital importance of leveling on a railroad survey it might be considered desirable to run a line of levels over the stadia stations in order that the leveling may be as precise as possible; but when it is considered that a preliminary survey is a somewhat hasty survey of a route that *may* be abandoned, and that the errors of leveling by the stadia method (which are compensating) may be so minimized that no proposed route would be abandoned on account of such small error, and that the effect of such an error may be easily neutralized by a slight change in the location, it may be seen that excessive care in the leveling of the preliminary survey is hardly justifiable.

Since the students taking this work are assumed to be familiar with the methods of stadia topographical surveys, this part of the subject will not be further elaborated.

14. "First" and "second" preliminary surveys. Some engineers advocate two preliminary surveys. When this is done,

the first is a very rapid survey, made perhaps with a compass, and is only a better grade of reconnoissance. Its aim is to rapidly develop the facts which will decide for or against any proposed route, so that if a route is found to be unfavorable another more or less modified route may be adopted without having wasted considerable time in the survey of useless details. By this time the student should have grasped the fundamental idea that both the reconnoissance and preliminary surveys are not surveys of *lines* but of *areas*; that their aim is to survey only those topographical features which would have a determining influence on any railroad line which might be constructed through that particular territory, and that the value of a locating engineer is largely measured by his ability to recognize those determining influences with the least amount of work from his surveying corps. Frequently too little time is spent on the comparative study of preliminary lines. A line will be hastily decided on after very little study; it will then be surveyed with minute detail and estimates carefully worked up, and the claims of any other suggested route will then be handicapped, if not disregarded, owing to an unwillingness to discredit and throw away a large amount of detailed surveying. The cost of two or three extra preliminary surveys (*at critical points* and not over the whole line) is utterly insignificant compared with the probable improvement in the "operating value" of a line located after such a comparative study of preliminary lines.

LOCATION SURVEYS.

15. "Paper location." When the preliminary survey has been plotted to a scale of 200 feet per inch and the contours drawn in, a study may be made for the location survey. Disregarding for the present the effect on location of transition curves, the alignment may be said to consist of straight lines (or "tangents") and circular curves. The "paper location" therefore consists in plotting on the preliminary map a succession of straight lines which are tangent to the circular curves connect-

ing them. The determining points should first be considered. Such points are the termini of the road, the lowest practicable point over a summit, a river-crossing, etc. So far as is possible, having due regard to other considerations, the road should be a "surface" road, i.e., the cut and fill should be made as small as possible. The maximum permissible grade must also have been determined and duly considered. The method of location differs radically according as the lines joining the determining points have a very low grade or have a grade that approaches the maximum permissible. With very low natural grades it is only necessary to strike a proper balance between the requirements for easy alignment and the avoidance of excessive earthwork. When the grade between two determined points approaches the maximum, a study of the location may be begun by finding a strictly surface line which will connect those points with a line at the given grade. For example, suppose the required grade is 1.6% and that the contours are drawn at 5-foot intervals. It will require 312 feet of 1.6% grade to rise 5 feet. Set a pair of dividers at 312 feet and step off this interval on successive contours. This line will in general be very irregular, but in an easy country it may lie fairly close to the proper location line, and even in difficult country such a surface line will assist greatly in selecting a suitable location. When the larger part of the line will evidently consist of tangents, the tangents should be first located and should then be connected by suitable curves. When the curves predominate, as they generally will in mountainous country, and particularly when the line is purposely lengthened in order to reduce the grade, the curves should be plotted first and the tangents may then be drawn connecting them. Considering the ease with which such lines may be drawn on the preliminary map, it is frequently advisable, after making such a paper location, to begin all over, draw a new line over some specially difficult section and compare results. Profiles of such lines may be readily drawn by noting their intersection with each contour crossed. Drawing on each profile the required grade line will furnish an approximate idea of the

comparative amount of earthwork required. After deciding on the paper location, the length of each tangent, the central angle (see § 21), and the radius of each curve should be measured as accurately as possible. Since a slight error made in such measurements, taken from a map with a scale of 200 feet per inch, would by accumulation cause serious discrepancies between the plotted location and the location as afterward surveyed in the field, frequent tie lines and angles should be determined between the plotted location line and the preliminary line, and the location should be altered, as may prove necessary, by changing the length of a tangent or changing the central angle or radius of a curve, so that the agreement of the check-points will be sufficiently close. The errors of an inaccurate preliminary survey may thus be easily neutralized (see § 33). When the preliminary line has been properly run, its "backbone" line will lie very near the location line and will probably cross it at frequent intervals, thus rendering it easy to obtain short and numerous tie lines.

16. Surveying methods. A transit should be used for alignment, and only precise work is allowable. The transit stations should be centered with tacks and should be tied to witness-stakes, which should be located outside of the range of the earthwork, so that they will neither be dug up nor covered up. All original property lines lying within the limits of the right of way should be surveyed with reference to the location line, so that the right-of-way agent may have a proper basis for settlement. When the property lines do not extend far outside of the required right of way they are frequently surveyed completely.

The leveler usually reads the target to the nearest thousandth of a foot on turning-points and bench-marks, but reads to the nearest tenth of a foot for the elevation of the ground at stations. Considering that $\frac{1}{1000}$ of a foot has an angular value of only 7 seconds at a distance of 300 feet, and that one division of a level-bubble is usually about 30 seconds, it may be seen that it is a useless refinement to read to thousandths unless corresponding care is taken in the use of the level. The leveler

should also locate his bench-marks outside of the range of earthwork. A knob of rock protruding from the ground affords an excellent mark. A large nail, driven in the roots of a tree, which is not to be disturbed, is also a good mark. These marks should be clearly described in the note-book. The leveler should obtain the elevation of the ground at all station-points; also at all sudden breaks in the profile line, determining also the distance of these breaks from the previous even station. This will include the position and elevation of all streams, and even dry gullies, which are crossed.

Measurements should preferably be made with a steel tape, care being taken on steep ground to insure horizontal measurements. Stakes are set each 100 feet, and also at the beginning and end of all curves. Transit-points (sometimes called "plugs" or "hubs") should be driven flush with the ground, and a "witness-stake," having the "number" of the station, should be set three feet to the right. For example, the witness-stake might have on one side " $137 + 69.92$," and on the other side " $P\ C\ 4^\circ\ R$," which would signify that the transit hub is 69.92 feet beyond station 137, or 13769.92 feet from the beginning of the line, and also that it is the "point of curve" of a " 4° -curve" which turns to the *right*.

Alignment. The alignment is evidently a part of the location survey, but, on account of the magnitude and importance of the subject, it will be treated in a separate chapter.

17. Form of Notes. Although the Form of Notes cannot be thoroughly understood until after curves are studied, it is here introduced as being the most convenient place. The right-hand page should have a sketch showing all roads, streams, and property lines crossed with the bearings of those lines. This should be drawn to a scale of 100 feet per inch—the quarter-inch squares which are usually ruled in note-books giving convenient 25-foot spaces. This sketch will always be more or less distorted on curves, since the center line is always shown as *straight* regardless of curves. The station points ("Sta." in first column, left-hand page) should be placed opposite to their

sketched positions, which means that even stations will be recorded on every *fourth* line. This allows three intermediate lines for substations, which is ordinarily more than sufficient. The notes should read up the page, so that the sketch will be properly oriented when looking ahead along the line. The other columns on the left-hand page will be self-explanatory when the subject of curves is understood. If the “calculated bearings” are based on azimuthal observations, their agreement (or *constant* difference) with the needle readings will form a valuable check on the curve calculations and the instrumental work.

FORM OF NOTES.

[Left-hand page.]

[Right-hand page.]

Sta.	Align- ment	Vernier	Tang. Defl.	Calc. Bearing.	Needle.	
54						
53 ⊙ + 72.2	P.T.	9° 11'	18° 22'	N 54° 48' E	N 62° 15' 1	
52		7 57				
51		6 15				
50 ⊙		4 33				
49		2 51				
48		1 09				
47 ⊙ + 32	P.C.	0°				
46				N 36° 26' E	N 44° 0' 1	

CHAPTER II.

ALIGNMENT.

alignement

IN this chapter the alignment of the *center line* only of a pair of rails is considered. When a railroad is crossing a summit in the grade line, although the horizontal projection of the alignment may be straight, the vertical projection will consist of two sloping lines joined by a curve. When a curve is on a grade, the center line is really a spiral, a curve of double curvature, although its horizontal projection is a circle. The center line therefore consists of straight lines and curves of single and double curvature. The simplest method of treating them is to consider their horizontal and vertical projections separately. In treating simple, compound, and transition curves, only the horizontal projections of those curves will be considered.

SIMPLE CURVES.

18. Designation of curves.

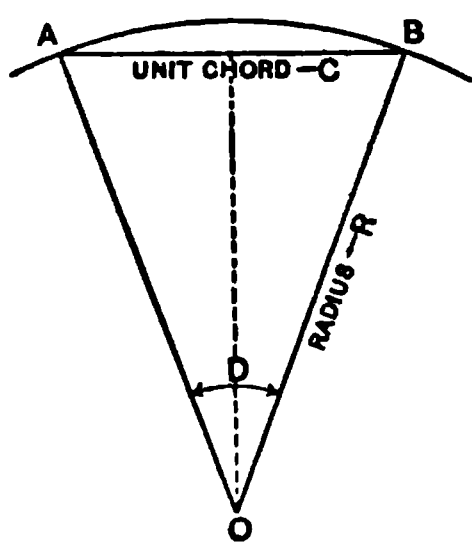


FIG. 7.

AB in Fig. 7 represents a unit chord (C) of a curve of radius R , then by the above defini-

tion the angle AOB equals D . Then $AO \sin \frac{1}{2}D = \frac{1}{2}AB = \frac{1}{2}C$.

$$\therefore R = \frac{\frac{1}{2}C}{\sin \frac{1}{2}D} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

or, by inversion,

$$\sin \frac{1}{2}D = \frac{C}{2R} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The unit chord is variously taken throughout the world as 100 feet, 66 feet, and 20 meters. In the United States 100 feet is invariably used as the unit chord length, and throughout this work it will be so considered. Table I has been computed on this basis. It gives the radius, with its logarithm, of all curves from a $0^\circ 01'$ curve up to a 10° curve, varying by single minutes. The sharper curves, which are seldom used, are given with larger intervals.

An approximate value of R may be readily found from the following simple rule, which should be memorized:

$$R = \frac{5730}{D}.$$

Although such values are not mathematically correct, since R does not strictly vary inversely as D , yet the resulting value is within a tenth of one per cent for all commonly used values of R , and is sufficiently close for many purposes, as will be shown later.

19. Length of a sub-chord. Since it is impracticable to measure along a curved arc, curves are always measured by laying off 100-foot chord lengths. This means that the actual arc is always a little longer than the chord. It also means that a *subchord* (a chord shorter than the unit length) will be a little longer than the ratio of the angles subtended would call for. The truth of this may be seen without calcu-

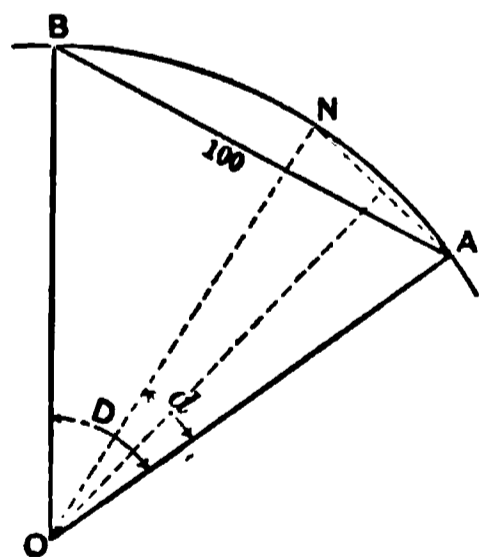


FIG. 8.

lation by noting that two equal subchords, each subtending the angle $\frac{1}{2}D$, will evidently be slightly longer than 50 feet each. If c be the length of a subchord subtending the angle d , then, as in Eq. (2),

$$\sin \frac{1}{2}d = \frac{c}{2R},$$

or, by inversion,

$$c = 2R \sin \frac{1}{2}d. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The *nominal length* of a subchord $= 100 \frac{d}{D}$. For example, a *nominal* subchord of 40 feet will subtend an angle of $\frac{40}{100}$ of D° ; its *true length* will be slightly more than 40 feet, and may be computed by Eq. 3. The *difference* between the nominal and true lengths is maximum when the subchord is about 57 feet long, but with the low degrees of curvature ordinarily used the difference may be neglected. With a 10° curve and a nominal chord length of 60 feet, the true length is 60.049 feet. Very sharp curves should be laid off with 50-foot or even 25-foot chords (nominal length). In such cases especially the true lengths of these subchords should be computed and used instead of the nominal lengths.

20. Length of a curve. The length of a curve is always indicated by the quotient of $100\Delta \div D$. If the quotient of $\Delta \div D$ is a whole number, the length as thus indicated is the true length—*measured in 100-foot chord lengths*. If it is an odd number or if the curve begins and ends with a subchord (even though $\Delta \div D$ is a whole number), theoretical accuracy requires that the *true* subchord lengths shall be used, although the difference may prove insignificant. The length of the arc (or the mean length of the two rails) is therefore always in excess of the length as given above. Ordinarily the amount of this excess is of no practical importance. It simply adds an insignificant amount to the length of rail required.

Example. Required the nominal and true lengths of a $3^\circ 45'$ curve having a central angle of $17^\circ 25'$. First reduce

the degrees and minutes to decimals of a degree. $(100 \times 17^\circ 25') \div 3^\circ 45' = 1741.667 \div 3.75 = 464.444$. The curve has four 100-foot chords and a nominal chord of 64.444. The true chord should be 64.451. The actual arc is

$$17^\circ.4167 \times \frac{\pi}{180^\circ} \times R = 464.527.$$

The excess is therefore $464.527 - 464.451 = 0.076$ foot.

21. Elements of a curve. Considering the line as running from A toward B , the beginning of the curve, at A , is called the *point of curve* (PC). The other end of the *curve*, at B , is called the *point of tangency* (PT).

The intersection of the tangents is called the *vertex* (V). The angle made by the tangents at V , which equals the angle made by the radii to the extremities of the curve, is called the *central angle* (Δ). AV and BV , the two equal tangents from the vertex to the PC and PT , are called the *tangent distances* (T). The chord AB is called the *long chord* (LC).

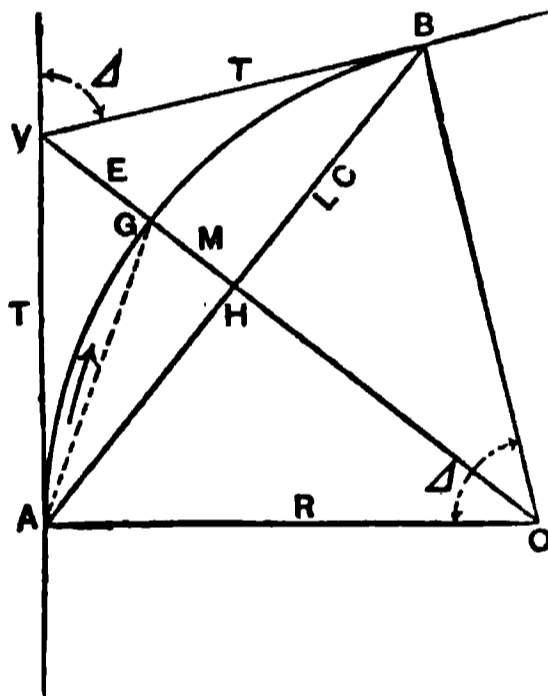


FIG. 9.

The intercept HG from the middle of the long chord to the middle of the arc is called the *middle ordinate* (M). That part of the secant GV from the middle of the arc to the vertex is called the *external distance* (E). From the figure it is very easy to derive the following frequently used relations:

$$T = R \tan \frac{1}{2}\Delta \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$LC = 2R \sin \frac{1}{2}\Delta \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$M = R \text{ vers } \frac{1}{2}\Delta \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$E = R \text{ exsec } \frac{1}{2}\Delta \quad . \quad . \quad . \quad . \quad . \quad (7)$$

22. Relation between T , E , and Δ . Join A and G in Fig. 9. The angle $VAG = \frac{1}{2}\Delta$, since it is measured by one half of the

arc AG between the secant and tangent. $AGO = 90^\circ - \frac{1}{2}\Delta$.

$$AV : VG :: \sin AGV : \sin VAG;$$

$$\sin AGV = \sin AGO = \cos \frac{1}{2}\Delta;$$

$$T : E :: \cos \frac{1}{2}\Delta : \sin \frac{1}{2}\Delta;$$

$$T = E \cot \frac{1}{2}\Delta. \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The same relation may be obtained by dividing Eq. 4 by Eq. 7, since $\tan \alpha \div \text{exsec } \alpha = \cot \frac{1}{2}\alpha$.

23. Elements of a 1° curve. From Eqs. 1 to 8 it is seen that the elements of a curve vary directly as R . It is also seen to be very nearly true that R varies inversely as D . If the elements of a 1° curve for various central angles are calculated and tabulated, the elements of a curve of D° curvature may be approximately found by dividing by D the corresponding elements of a 1° curve having the same central angle. For small central angles and low degrees of curvature the errors involved by the approximation are insignificant, and even for larger angles the errors are so small that *for many purposes* they may be disregarded.

In Table II is given the value of the tangent distances, external distances, and long chords for a 1° curve for various central angles. The student should familiarize himself with the degree of approximation involved by solving a large number of cases under various conditions by the exact and approximate methods, in order that he may know when the approximate method is sufficiently exact for the intended purpose. The approximate method also gives a ready check on the exact method.

24. Exercises. (a) What is the tangent distance of a $4^\circ 20'$ curve having a central angle of $18^\circ 24'$?

(b) Given a $3^\circ 30'$ curve and a central angle of $16^\circ 20'$, how far will the curve pass from the vertex? [Use Eq. 7.]

(c) An 18° curve is to be laid off using 25-foot (nominal) chord lengths. What is the true length of the subchords?

(*d*) Given two tangents making a central angle of $15^\circ 24'$. It is desired to connect these tangents by a curve which shall pass 16.2 feet from their intersection. How far down the tangent will the curve begin and what will be its radius? (Use Eq. 8 and then use Eq. 4 inverted.)

25. Curve location by deflections. The angle between a secant and a tangent (or between two secants intersecting on an arc) is measured by one half of the intercepted arc. Beginning at the *PC* (*A* in Fig. 10), if the first chord is to be a full chord we may deflect an angle $V A a (= \frac{1}{2} D)$, and the point *a*, which is 100 feet from *A*, is a point on the curve. For the next station, *b*, deflect an *additional* angle $b A a (= \frac{1}{2} D)$ and, with one end of the tape at *a*, swing the other end until the 100-foot point is on the line *Ab*. The point *b* is then on the curve. If the final chord *cB* is a subchord, its *additional deflection* ($\frac{1}{2} \alpha$) is something less than $\frac{1}{2} D$. The last *deflection* ($B A V$) is of course $\frac{1}{2} \Delta$. It is particularly important, when a curve begins or ends with a subchord and the deflections are odd quantities, that the last additional deflection should be carefully computed and added to the previous deflection, to check the mathematical work by the agreement of this last computed deflection with $\frac{1}{2} \Delta$.

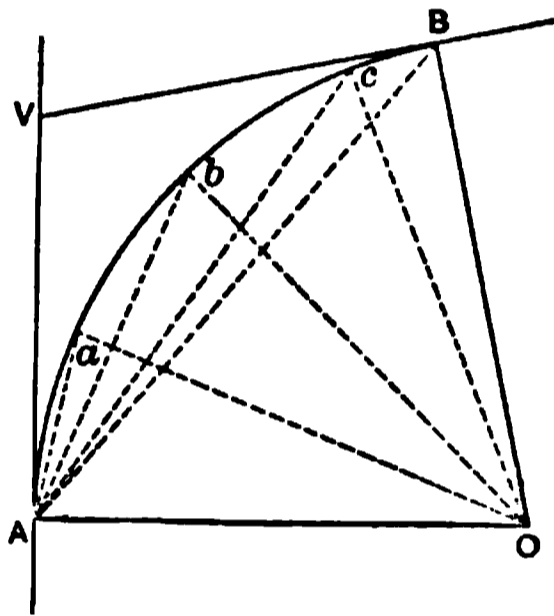


FIG. 10.

Example. Given a $3^\circ 24'$ curve having a central angle of $18^\circ 22'$ and beginning at sta. $47 + 32$, to compute the deflections. The nominal length of curve is $18^\circ 22' \div 3^\circ 24' = 18.367 \div 3.40 = 5.402$ stations or 540.2 feet. The curve therefore ends at sta. $52 + 72.2$. The deflection for sta. 48 is $\frac{68}{100} \times \frac{1}{2}(3^\circ 24') = 0.68 \times 1^\circ.7 = 1^\circ.156 = 1^\circ 09'$ nearly. For each additional 100 feet it is $1^\circ 42'$ additional. The final additional deflection for the final subchord of 72.2 feet is

$$\frac{72.2}{100} \times \frac{1}{2}(3^\circ 24') = 1^\circ.2274 = 1^\circ 14' \text{ nearly.}$$

The deflections are

P. C Sta. 47 + 32	0°
48	0° + 1° 09' = 1° 09'
49	1° 09' + 1° 42' = 2° 51'
50	2° 51' + 1° 42' = 4° 33'
51	4° 33' + 1° 42' = 6° 15'
52	6° 15' + 1° 42' = 7° 57'
P. T 52 + 72.2	7° 57' + 1° 14' = 9° 11'

As a check $9^{\circ} 11' = \frac{1}{2}(18^{\circ} 22') = \frac{1}{2} \Delta$. (See the Form of Notes in § 17.)

26. Instrumental work. It is generally impracticable to locate more than 500 to 600 feet of a curve from one station. Obstructions will sometimes require that the transit be moved up every 200 or 300 feet. There are two methods of setting off the angles when the transit has been moved up from the *PC*.

(a) The transit may be sighted at the previous transit station with a reading on the plates equal to the deflection angle from that station to the station occupied, but with the angle set off on the *other* side of 0°, so that when the telescope is turned to 0° it will sight along the tangent at the station occupied. Plunging the telescope, the forward stations may be set off by deflecting the proper deflections from the tangent at the station occupied. This is a very common method and, when the degree of curvature is an even number of degrees and when the transit is only set at even stations, there is but little objection to it. But the degree of curvature is sometimes an odd quantity, and the exigencies of difficult location frequently require that substations be occupied as transit stations. Method (a) will then require the recalculation of all deflections for each new station occupied. The mathematical work is largely increased and the probability of error is very greatly increased and not so easily detected. Method (b) is just as simple as method (a) even for the most simple cases, and for the more difficult cases just referred to the superiority is very great.

(b) Calculate the deflection for each station and substation throughout the curve as though the whole curve were to be located from the *PC*. The computations may thus be completed and *checked* (as above) before beginning the instrumental work. If it unexpectedly becomes necessary to introduce a substation at any point, its deflection from the *PC* may be readily interpolated. The stations actually set from the *PC* are located as usual. **RULE.** When the transit is set on any forward station, backsight to **ANY** previous station with the plates set at the deflection angle for the station sighted at. Plunge the telescope and sight at any forward station with the deflection angle originally computed for that station. When the plates read the deflection angle for the station occupied, the telescope is sighting along the tangent at that station—which is the method of getting the forward tangent when occupying the *PT*. Even though the station occupied is an unexpected substation, when the instrument is properly oriented at that station, the angle reading for *any* station, forward or back, is that originally computed for it from the *PC*. In difficult work, where there are obstructions, a valuable check on the accuracy may be found by sighting backward at *any* visible station and noting whether its deflection agrees with that originally computed. As a numerical illustration, assume a 4° curve, with 28° curvature, with stations 0, 2, 4, and 7 occupied. After setting stations 1 and 2, set up the transit at sta. 2 and backsight to sta. 0 with the deflection for sta. 0, which is 0° . The reading on sta. 1 is 2° ; when the reading is 4° the telescope is tangent to the curve, and when sighting at 3 and 4 the deflections will be 6° and 8° .

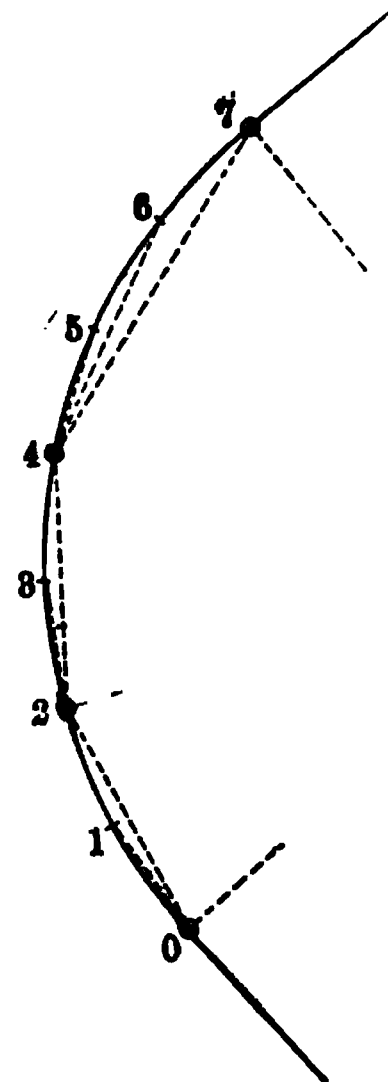


FIG. 11.

Occupy 4; sight to 2 with a reading of 4° . When the reading is 8° the telescope is tangent to the curve and, by plunging the telescope, 5, 6, and 7 may be located with the originally com-

puted deflections of 10° , 12° , and 14° . When occupying T a backsight may be taken to any visible station with the plates reading the deflection for that station; then when the plates read 14° the telescope will point along the forward tangent.

The location of curves by deflection angles is the normal method. A few other methods, to be described, should be considered as exceptional.

27. Curve location by two transits. A curve might be located more or less on a swamp where accurate chaining would be exceedingly difficult if not impossible. The long chord AB may be determined by triangulation or otherwise, and the elements of

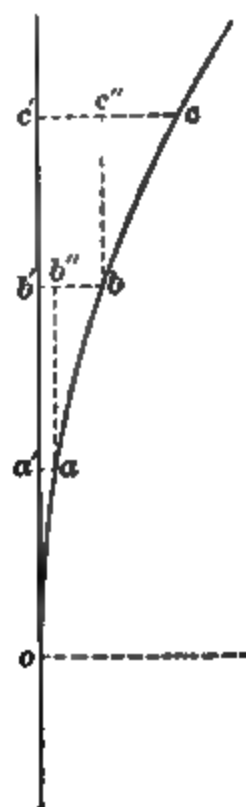


FIG. 18.

FIG. 19.

the curve computed, including (possibly) subchords at each end. The deflection from A and B to each point may be computed. A rodman may then be sent (by whatever means) to locate long stakes at points determined by the simultaneous sightings of the two transits.

28. Curve location by tangential offsets. When a curve is very flat and no transit is at hand the following method may be

used: Produce the back tangent as far forward as necessary. Compute the ordinates Oa' , Ob' , Oc' , etc., and the abscissæ $a'a$, $b'b$, $c'c$, etc. If Oa is a full station (100 feet), then

$$\left. \begin{aligned} Oa' &= Oa' &= 100 \cos \frac{1}{2}D, \text{ also } = R \sin D; \\ Ob' &= Oa' + a'b' &= 100 \cos \frac{1}{2}D + 100 \cos \frac{3}{2}D, \\ & &\text{also } = R \sin 2D; \\ Oc' &= Oa' + a'b' + b'c' = 100(\cos \frac{1}{2}D + \cos \frac{3}{2}D + \cos \frac{5}{2}D), \\ & &\text{also } = R \sin 3D; \end{aligned} \right\} \quad (9)$$

etc.

$$\left. \begin{aligned} a'a &= &100 \sin \frac{1}{2}D, \text{ also } = R \text{ vers } D; \\ b'b &= a'a + b''b &= 100 \sin \frac{1}{2}D + 100 \sin \frac{3}{2}D, \\ & &\text{also } = R \text{ vers } 2D; \\ c'c &= b'b + c''c &= 100(\sin \frac{1}{2}D + \sin \frac{3}{2}D + \sin \frac{5}{2}D), \\ & &\text{also } = R \text{ vers } 3D; \end{aligned} \right\} \quad (10)$$

etc.

The functions $\frac{1}{2}D$, $\frac{3}{2}D$, etc., may be more conveniently used *without* logarithms, by adding the several *natural* trigonometrical functions and pointing off two decimal places. It may also be noted that ob' (for example) is one half of the long chord for four stations; also that $b'b$ is the middle ordinate for four stations. If the engineer is provided with tables giving the long chords and middle ordinates for various degrees of curvature, these quantities may be taken (perhaps by interpolation) from such tables.

If the curve begins or ends at a substation, the angles and terms will be correspondingly altered. The modifications may be readily deduced on the same principles as above, and should be worked out as an exercise by the student.

29. Curve location by middle ordinates. Take first the simpler case when the curve begins at an even station. If we consider (in Fig. 14) the curve produced back to z , the chord $za = 2 \times 100 \cos \frac{1}{2}D$, $A'a = 100 \cos \frac{1}{2}D$, and $A'A = am = zn = 100 \sin \frac{1}{2}D$. Set off AA' perpendicular to the tangent and $A'a$ parallel to the tangent. $AA' = aa' = bb' = cc'$, etc. $= 100 \sin \frac{1}{2}D$. Set off aa' perpendicular to $a'A$. Produce Aa'

until $a'b = A'a$, thus determining b . Succeeding points of the curve may thus be determined indefinitely.

Suppose the curve begins with a subchord. As before $ra = Am' = c' \cos \frac{1}{2}d'$, and $rA = am' = c' \sin \frac{1}{2}d'$. Also $sz = An' = c'' \cos \frac{1}{2}d''$, and $sA = zn' = c'' \sin \frac{1}{2}d''$, in which

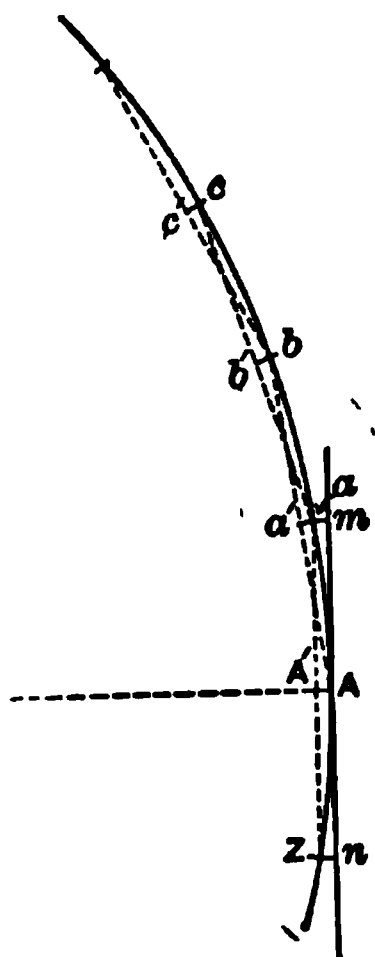


FIG. 14.

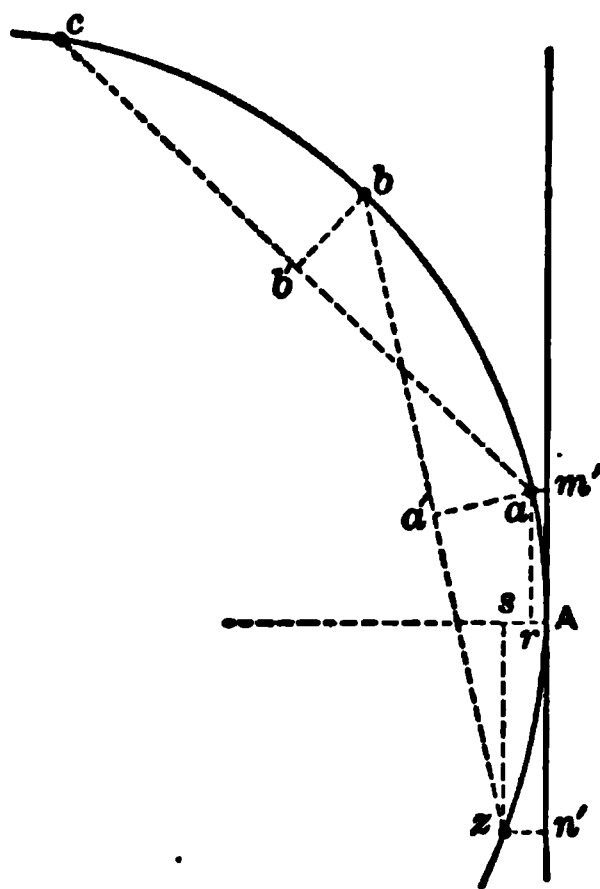


FIG. 15.

$(d' + d'') = D$. The points z and a being determined on the ground, aa' may be computed and set off as before and the curve continued in full stations. A subchord at the end of the curve may be located by a similar process.

30. Curve location by offsets from the long chord. (Fig. 16.) Consider at once the general case in which the curve commences with a subchord (curvature, d'), contains with one or more full chords (curvature of each, D), and ends with a subchord with curvature d'' . The numerical work consists in computing first AB , then the various abscissæ and ordinates. $AB = 2R \sin \frac{1}{2}\Delta$.

$$\begin{aligned}
 Aa' &= Aa' &= c' \cos \frac{1}{2}(\Delta - d'); \\
 Ab' &= Aa' + a'b' &= c' \cos \frac{1}{2}(\Delta - d') + 100 \cos \frac{1}{2}(\Delta - 2d' - D); \\
 Ac' &= Aa' + a'b' + b'c' &= c' \cos \frac{1}{2}(\Delta - d') + 100 \cos \frac{1}{2}(\Delta - 2d' - D) \\
 & &+ 100 \cos \frac{1}{2}(\Delta - 2d'' - D); \\
 \text{also} & & \\
 &= AB - Bc' &= 2R \sin \frac{1}{2}\Delta - c'' \cos \frac{1}{2}(\Delta - d'').
 \end{aligned}
 \tag{11}$$

$$\begin{aligned}
 a'a &= a'a = c' \sin \frac{1}{2}(\Delta - d'); \\
 b'b &= a'a + mb = c' \sin \frac{1}{2}(\Delta - d') + 100 \sin \frac{1}{2}(\Delta - 2d' - D); \\
 c'c &= b'b - nb = c' \sin \frac{1}{2}(\Delta - d') + 100 \sin \frac{1}{2}(\Delta - 2d' - D) \\
 &\quad - 100 \sin \frac{1}{2}(\Delta - 2d'' - D); \\
 \text{also} \quad &= c'' \sin \frac{1}{2}(\Delta - d'').
 \end{aligned}
 \quad \left. \vphantom{\begin{aligned} a'a \\ b'b \\ c'c \end{aligned}} \right\} (12)$$

The above formulæ are considerably simplified when the curve begins and ends at even stations. When the curve is very long a regular law becomes very apparent in the formation of all terms between the first and last. There are too few terms in the above equations to show the law.

31. Use and value of the above methods. The chief value of the above methods lies in the possibility of doing the work without a transit. The same principles are sometimes employed, even when a transit is used, when obstacles prevent the use of the normal method (see § 32, c). If the terminal tangents have already been accurately determined, these methods are useful to locate points of the curve when rigid accuracy is not essential. Track foremen frequently use such methods to lay out unimportant sidings, especially when the engineer and his transit are not at hand. Location by tangential offsets (or by offsets from the long chord) is to be preferred when the curve is flat (i.e., has a small central angle Δ) and there is no obstruction along the tangent, or long chord. Location by middle ordinates may be employed regardless of the length of the curve, and in cases when both the tangents and the long chord are obstructed. The above methods are but samples of a large number of similar methods which have been devised. The choice of the particular method to be adopted must be determined by the local conditions.

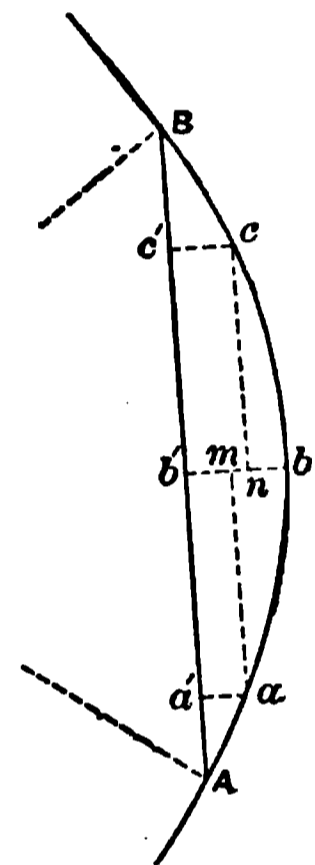


FIG. 16.

32. Obstacles to location. In this section will be given only a few of the principles involved in this class of problems, with illustrations. The engineer must decide in each case, which is

the best method to use, and it is frequently advisable to devise a special solution for some particular case.

a. When the vertex is inaccessible. As shown in § 26, it is not absolutely essential that the vertex of a curve should be located on the ground. But it is very evident that the angle between the terminal tangents is determined with far less probable error if it is measured by a single measurement at the vertex rather than as the result of numerous angle measurements along the curve, involving several positions of the transit and comparatively short sights. Sometimes the location of the tangents is already determined on the ground (as by bn and am , Fig. 17), and it is required to join the tangents by a curve of given radius. *Method.* Measure ab and the angles Vba and baV . Δ is the sum of these angles. The distances bV and aV are computable from the above data. Given Δ and R , the tan-

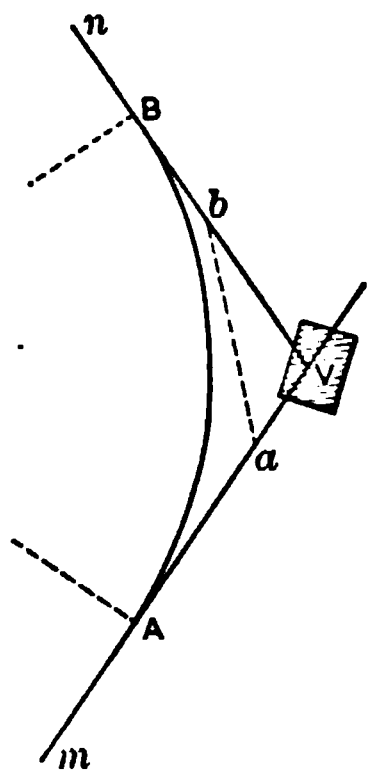


FIG. 17.

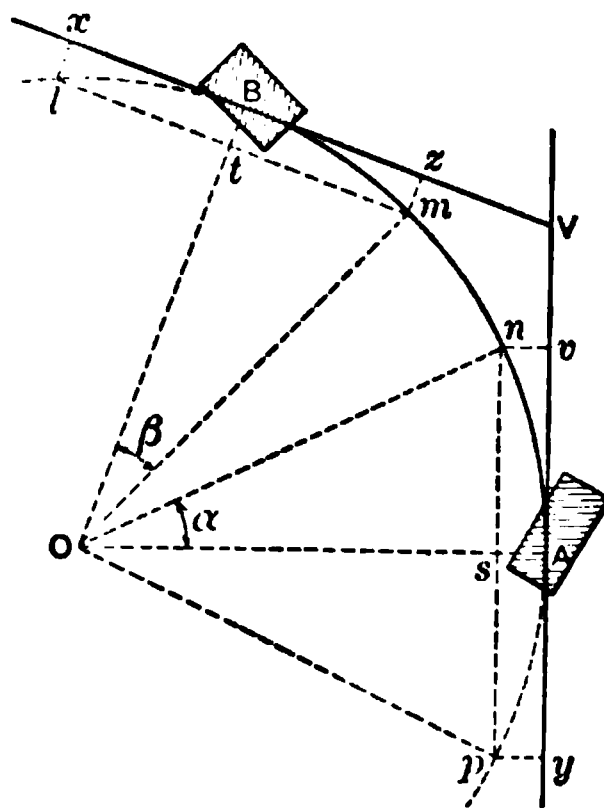


FIG. 18.

gent distances are computable, and then Bb and aA are found by subtracting bV and aV from the tangent distances. The curve may then be run from A , and the work may be checked by noting whether the curve as run ends at B —previously located from b .

b. When the point of curve (or point of tangency) is inaccessible. At some distance (As , Fig. 18) an unobstructed line pn

may be run parallel with AV . $nv = py = As = R \text{ vers } \alpha$.

$$\therefore \text{vers } \alpha = As \div R. \quad ns = ps = R \sin \alpha.$$

At y , which is at a distance ps back from the *computed* position of A , make an offset sA to p . Run pn parallel to the tangent. A tangent to the curve at n makes an angle of α with np . From n the curve is run in as usual.

If the point of tangency is obstructed, a similar process, somewhat reversed, may be used. β is that portion of Δ still to be laid off when m is reached. $tm = tl = R \sin \beta$. $mz = tB = lx = R \text{ vers } \beta$.

c. **When the central part of the curve is obstructed.** α is the central angle between two points of the curve between which a chord may be run. α may equal *any* angle, but it is preferable that α should be a multiple of D , the degree of curve, and that the points m and n should be on even stations. $mn = 2R \sin \frac{1}{2}\alpha$. A point s may be located by an offset ks from the chord mn by a similar method to that outlined in § 30.

The device of introducing the dotted curve mn having the same radius of curvature as the other, although neither necessary nor advisable in the case shown in Fig. 19, is sometimes the best method of surveying around an obstacle. The offset from any point on the dotted curve to the corresponding point on the true curve is twice the "ordinate to the long chord," as computed in § 30.

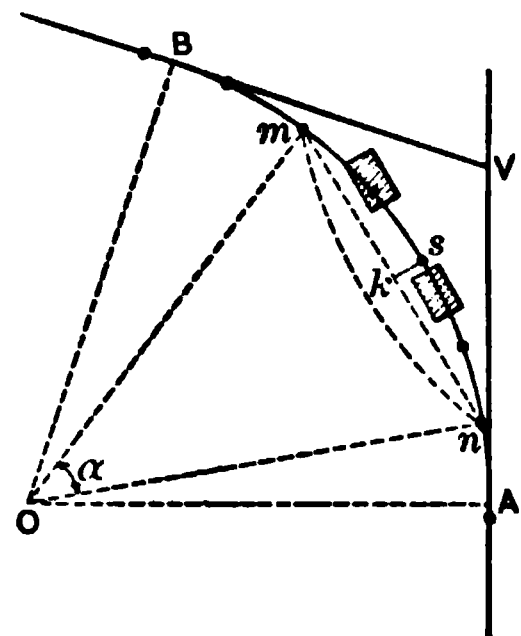


FIG. 19.

33. Modifications of location. The following methods may be used in allowing for the discrepancies between the "paper location" based on a more or less rough preliminary survey and the more accurate instrumental location. (See § 15.) They are also frequently used in locating new parallel tracks and modifying old tracks.

a. To move the forward tangent parallel to itself a distance x , the point of curve (A) remaining fixed. (Fig. 20.)

$$V'h = B'r = x'.$$

$$VV' = \frac{V'h}{\sin h VV'} = \frac{x'}{\sin \Delta} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$AV' = AV + VV'.$$

The triangle BmB' is isosceles and $Bm = B'm$.

$$R' - R = O'O = mB = \frac{B'r}{\text{vers } B'mB} = \frac{x'}{\text{vers } \Delta}$$

$$\therefore R' = R + \frac{x'}{\text{vers } \Delta} \quad . \quad . \quad . \quad . \quad (14)$$

The solution is very similar in case the tangent is moved inward to $V''B''$. Note that this method necessarily changes the

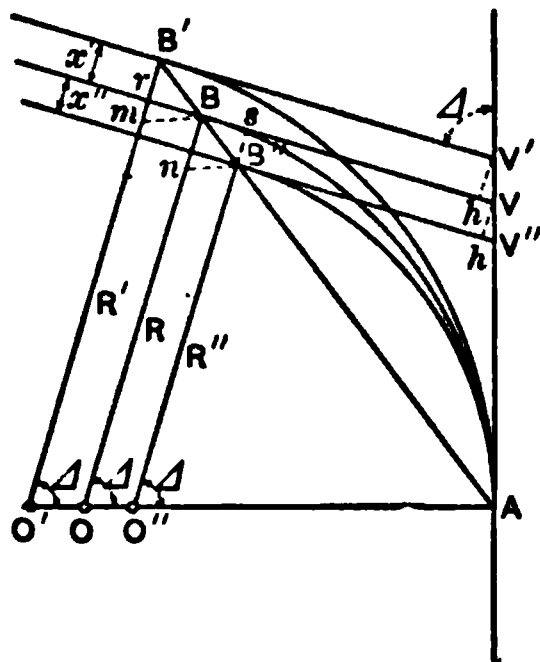


FIG. 20.

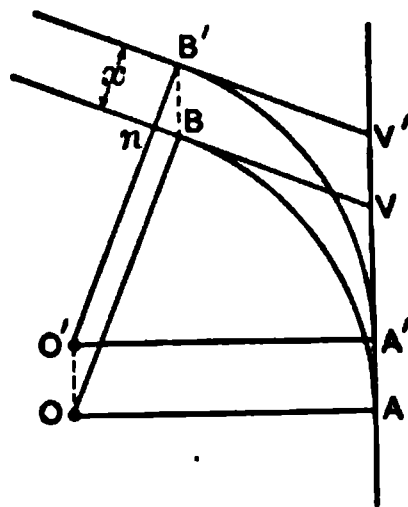


FIG. 21.

radius. If the radius is not to be changed, the point of curve must be altered as follows:

b. To move the forward tangent parallel to itself a distance x , the radius being unchanged. (Fig. 21.) In this case the whole

curve is moved bodily a distance $OO' = AA' = VV' = BB'$, and moved parallel to the first tangent AV .

$$BB' = \frac{B'n}{\sin nBB'} = \frac{x}{\sin \Delta} = AA'. \quad . \quad . \quad (15)$$

c. To change the direction of the forward tangent at the point of tangency. (Fig. 22.) This problem involves a change (α) in the central angle and also requires a new radius. An error in the determination of the central angle furnishes an occasion for its use.

R , Δ , α , AV , and BV are known. $\Delta' = \Delta - \alpha$.

$$Bs = R \text{ vers } \Delta. \quad Bs = R' \text{ vers } \Delta'.$$

$$\therefore R' = R \frac{\text{vers } \Delta}{\text{vers } (\Delta - \alpha)}. \quad . \quad . \quad . \quad (16)$$

$$As = R \sin \Delta. \quad A's = R' \sin \Delta'.$$

$$\therefore AA' = A's - As = R' \sin \Delta' - R \sin \Delta. \quad . \quad (17)$$

The above solutions are given to illustrate a large class of problems which are constantly arising. All of the ordinary

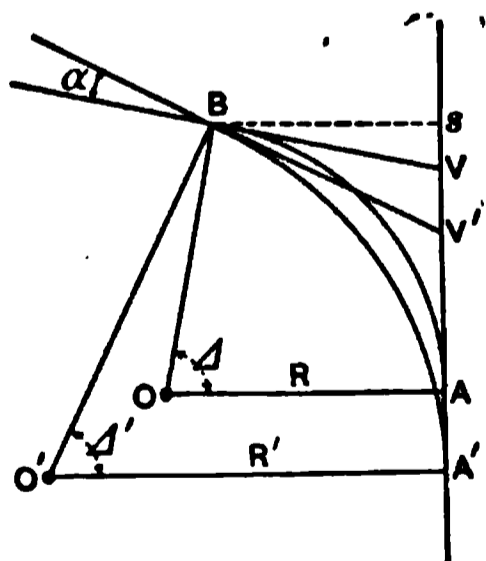


FIG. 22.

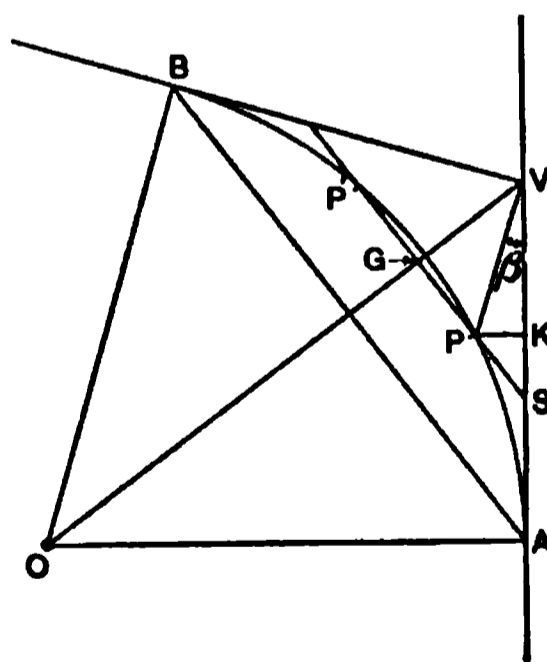


FIG. 23.

problems can be solved by the application of elementary geometry and trigonometry.

34. Limitations in location. It may be required to run a curve that shall join two given tangents and also pass through a given point. The point (P , Fig. 23) is assumed to be determined by its distance (VP) from the vertex and by the angle $\angle V P = \beta$.

It is required to determine the radius (R) and the tangent distance (AV). Δ is known.

$$PVG = \frac{1}{2}(180^\circ - \Delta) - \beta = 90^\circ - (\frac{1}{2}\Delta + \beta).$$

$$PP' = 2 VP \sin PVG = 2 VP \cos (\frac{1}{2}\Delta + \beta).$$

$$PSV = \frac{1}{2}\Delta. \quad \therefore SP = VP \frac{\sin \beta}{\sin \frac{1}{2}\Delta}.$$

$$AS = \sqrt{SP \times SP'} = \sqrt{SP(SP + PP')}.$$

$$= \sqrt{VP \frac{\sin \beta}{\sin \frac{1}{2}\Delta} \left[VP \frac{\sin \beta}{\sin \frac{1}{2}\Delta} + 2 VP \cos (\frac{1}{2}\Delta + \beta) \right]}$$

$$= VP \sqrt{\frac{\sin^2 \beta}{\sin^2 \frac{1}{2}\Delta} + \frac{2 \sin \beta \cos (\frac{1}{2}\Delta + \beta)}{\sin \frac{1}{2}\Delta}}.$$

$$SV = VP \frac{\sin (\frac{1}{2}\Delta + \beta)}{\sin \frac{1}{2}\Delta}.$$

$$AV = AS + SV$$

$$= \frac{VP}{\sin \frac{1}{2}\Delta} [\sin (\frac{1}{2}\Delta + \beta) + \sqrt{\sin^2 \beta + 2 \sin \beta \sin \frac{1}{2}\Delta \cos (\frac{1}{2}\Delta + \beta)}]. \quad (18)$$

$$R = AV \cot \frac{1}{2}\Delta.$$

In the special case in which P is on the median line OV , $\beta = 90^\circ - \frac{1}{2}\Delta$, and $(\frac{1}{2}\Delta + \beta) = 90^\circ$. Eq. (18) then reduces to

$$AV = \frac{VP}{\sin \frac{1}{2}\Delta} (1 + \cos \frac{1}{2}\Delta) = VP \cot \frac{1}{4}\Delta,$$

as might have been immediately derived from Eq. (8).

In case the point P is given by the offset PK and by the distance VK , the triangle PKV may be readily solved, giving the distance VP and the angle β , and the remainder of the solution will be as above.

35. Determination of the curvature of existing track. (a) *Using a transit.* Set up the transit at any point in the center of the track. Measure in each direction 100 feet to points also in the center of the track. Sight on one point with the plates at 0° . Plunge the telescope and sight at the other point. The angle between the chords equals the degree of curvature.

(b) *Using a tape and string.* Stretch a string (say 50 feet long) between two points on the inside of the head of the outer rail. Measure the ordinate (x) between the *middle* of the string and the head of the rail. Then

$$R = \frac{\text{chord}^2}{8x} \text{ (very nearly).} \quad . \quad . \quad . \quad (19)$$

For, in Fig. 24, since the triangles AOE and ADC are similar, $AO : AE :: AD : DC$ or $R = \frac{1}{2}AD^2 \div x$. When, as is usual, the arc is very short compared with the radius, $AD = \frac{1}{2}AB$, very nearly. Making this substitution we have Eq. (19). With a chord of 50 feet and a 10° curve, the resulting difference in x is .0025 of an inch—far within the possible accuracy of such a method. The above method gives the radius of the inner head of the outer rail. It should be diminished by $\frac{1}{2}g$ for the radius of the center of the track. With easy curvature, however, this will not affect the result by more than one or two tenths of one per cent.

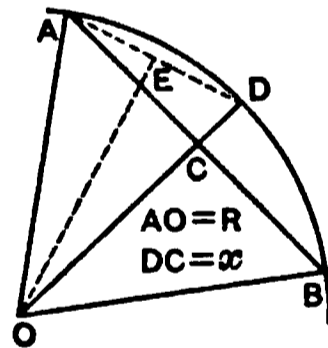


FIG. 24.

The inversion of this formula gives the required middle ordinate for a rail on a given curve. For example, the middle ordinate of a 30-foot rail, bent for a 6° curve, is

$$x = 900 \div (8 \times 955) = .118 \text{ foot} = 1.4 \text{ inches.}$$

Another much used rule is to require the foreman to have a string, knotted at the centre, of such length that the middle ordinate, measured in inches, equals the degree of curve. To find that length, substitute (in eq. (19)) $5730 \div D$ for R and $D \div 12$ for x . Solving for *chord*, we obtain *chord* = 61.8 feet. The rule is not theoretically exact, but, considering the uncertain stretching of the string, the error is insignificant. In fact, the distance usually given is 62 feet, which is close enough for all purposes for which such a method should be used.

36. Problems. A systematic method of setting down the solution of a problem simplifies the work. Logarithms should always be used, and *all* the work should be so set down that a revision of the work to find a supposed error may be readily done. The value of such systematic work will become more apparent as the problems become more complicated. The two solutions given below will illustrate such work.

a. Given a 3° curve beginning at Sta. $27 + 60$ and running to Sta. $32 + 45$. Compute the ordinates and offsets used in locating the curve by tangential offsets.

b. With the same data as above, compute the distances to locate the curve by offsets from the long chord.

c. Assume that in Fig. 17 ab is measured as 217.6 feet, the angle $abV = 17^\circ 42'$, and the angle $baV = 21^\circ 14'$. Join the tangents by a $4^\circ 30'$ curve. Determine bB and aA .

d. Assume that in a case similar to Fig. 18 it was noted that a distance (As) equal to 12 feet would clear the building. Assume that $\angle = 38^\circ 20'$ and that $D = 4^\circ 40'$. Required the value of α and the position of n . *Solution:*

vers $\alpha = As \div R$	$As = 12$	log = 1.07918
	R (for $4^\circ 40'$ curve)	log = 3.08923
	<u>$\alpha = 8^\circ 01'$</u>	<u>log vers $\alpha = 7.98994$</u>
$ns = R \sin \alpha$		log sin $\alpha = 9.14445$
		log $R = 3.08923$
	<u>$ns = 171.27$</u>	<u>log = 2.23369</u>

e. Assume that the forward tangent of a $3^\circ 20'$ curve having a central angle of $16^\circ 50'$ must be moved 3.62 feet *inward*, without altering the *P.C.* Required the change in radius.

f. Given two tangents making an angle of $36^\circ 18'$. It is required to pass a curve through a point 93.2 feet from the vertex, the line from the vertex to the point making an angle of $42^\circ 21'$ with the tangent. Required the radius and tangent distance. *Solution:* Applying eq. (18), we have

2	$\log = 0.30103$
$\beta = 42^\circ 21'$	$\log \sin = 9.82844$
$\frac{1}{2}\Delta = 18^\circ 09'$	$\log \sin = 9.49346$
$(\frac{1}{2}\Delta + \beta) = 60^\circ 30'$	$\log \cos = 9.69234$
$.20667$	<u><u>9.31527</u></u>
$\log \sin^2 \beta = 9.65688 \dots \dots .45382$	
$2 \mid 9.81987 \dots \dots .66049$	
<u>$9.90993 \dots \dots .81271$</u>	
$\text{nat} \sin 60^\circ 30' = .8703$	
<u>1.6836</u>	$\log = \overline{0.22610}$
$VP = 93.2$	$\log = 1.96941$
	<u>2.19551</u>
	$\log \sin \frac{1}{2}\Delta = 9.49346$
<u>tang. dist. $AV = 503.56$</u>	$\log = 2.70205$
	$\log \cot \frac{1}{2}\Delta = 10.48437$
	<u>3.18642</u>
$R = 1536.1$	
<u>$D = 3^\circ 44'$</u>	

COMPOUND CURVES.

37. Nature and use. Compound curves are formed by a succession of two or more simple curves of different curvature. The curves must have a common tangent at the point of compound curvature (*P.C.C.*). In mountainous regions there is frequently a necessity for compound curves having several changes of curvature. Such curves may be located separately as a succession of simple curves, but a combination of two

simple curves has special properties which are worth investigating and utilizing. In the following demonstrations R_2 always represents the *longer* radius and R_1 the *shorter*, no matter which succeeds the other. T_1 is the tangent adjacent to the curve of shorter radius (R_1), and is invariably the shorter tangent. Δ_1 is the central angle of the curve of radius R_1 , but it may be greater or less than Δ_2 .

38. Mutual relations of the parts of a compound curve having two branches. In Fig. 25, AC and CB are the two branches of

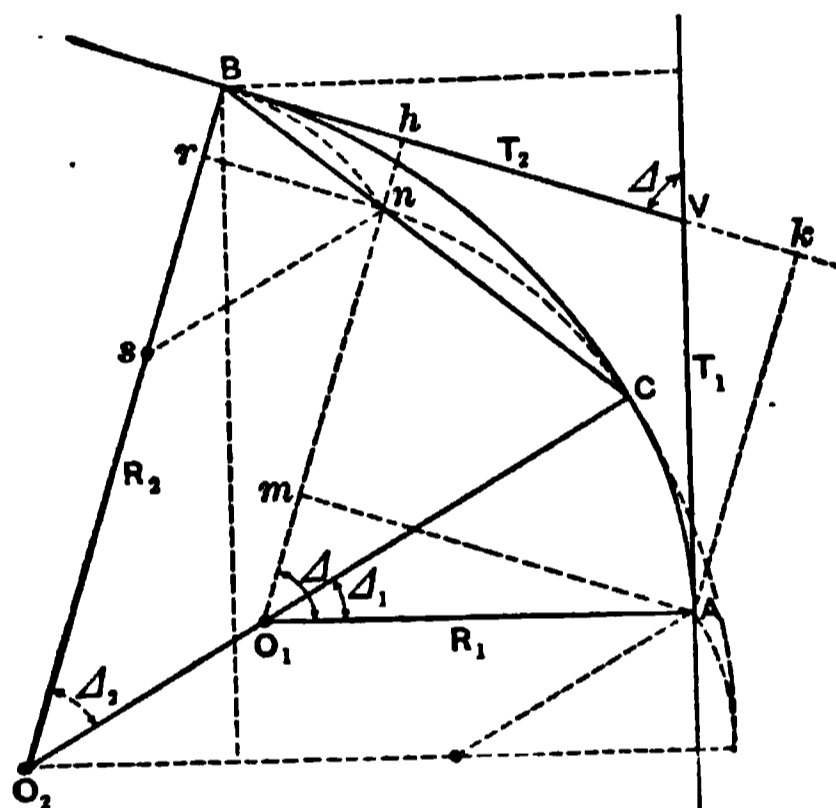


FIG 25.

the compound curve having radii of R_1 and R_2 and central angles of Δ_1 and Δ_2 . Produce the arc AC to n so that $AO_1n = \Delta$. The chord Cn produced *must* intersect B . The line ns , parallel to CO_2 , will intersect BO_2 so that $Bs = sn = O_2O_1 = R_2 - R_1$. Draw Am perpendicular to O_1n . It will be parallel to hk .

$$Br = sn \text{ vers } Bsn = (R_2 - R_1) \text{ vers } \Delta_2;$$

$$mn = AO_1 \text{ vers } AO_1n = R_1 \text{ vers } \Delta;$$

$$Ak = AV \sin AVk = T_1 \sin \Delta;$$

$$Ak = hm = mn + nh = mn + Br.$$

$$\therefore T_1 \sin \Delta = R_1 \text{ vers } \Delta + (R_2 - R_1) \text{ vers } \Delta_2. \quad (20)$$

Similarly it may be shown that

$$T_1 \sin \Delta = R_2 \text{ vers } \Delta - (R_2 - R_1) \text{ vers } \Delta_1. \quad (21)$$

The mutual relations of the elements of compound curves may be solved by these two equations. For example, assume the tangents as fixed (Δ therefore known) and that a curve of given radius R_1 shall start from a given point at a distance T_1 from the vertex, and that the curve shall continue through a given angle Δ_1 . Required the other parts of the curve. From Eq. (20) we have

$$R_2 - R_1 = \frac{T_1 \sin \Delta - R_1 \text{ vers } \Delta}{\text{vers } \Delta_1}.$$

$$\therefore R_2 = R_1 + \frac{T_1 \sin \Delta - R_1 \text{ vers } \Delta}{\text{vers } (\Delta - \Delta_1)}. \quad (22)$$

T_1 may then be obtained from Eq. (21).

As another problem, given the location of the two tangents, with the two tangent distances (thereby locating the PC and PT), and the central angle of each curve; required the two radii. Solving Eq. (20) for R_1 , we have

$$R_1 = \frac{T_1 \sin \Delta - R_2 \text{ vers } \Delta_1}{\text{vers } \Delta - \text{vers } \Delta_1}.$$

Similarly from Eq. (21) we may derive

$$R_1 = \frac{T_1 \sin \Delta - R_2 (\text{vers } \Delta - \text{vers } \Delta_1)}{\text{vers } \Delta_1}.$$

Equating these, reducing, and solving for R_2 , we have

$$R_2 = \frac{T_1 \sin \Delta \text{ vers } \Delta_1 - T_1 \sin \Delta (\text{vers } \Delta - \text{vers } \Delta_1)}{\text{vers } \Delta_1 \text{ vers } \Delta_1 - (\text{vers } \Delta - \text{vers } \Delta_1)(\text{vers } \Delta - \text{vers } \Delta_1)}. \quad (23)$$

Although the various elements may be chosen as above with considerable freedom, there are limitations. For example, in Eq. (22), since R_2 is always greater than R_1 , the term to be added to R_1 must be essentially positive—i.e., $T_1 \sin \Delta$ must be

greater than $R_1 \text{ vers } \Delta$. This means that $T_1 > R_1 \frac{\text{vers } \Delta}{\sin \Delta}$, or that $T_1 > R_1 \tan \frac{1}{2}\Delta$, or that T_1 is greater than the corresponding tangent on a simple curve. Similarly it may be shown that T_1 is *less* than $R_1 \tan \frac{1}{2}\Delta$ or *less* than the corresponding tangent on a simple curve. Nevertheless T_1 is always greater than T_2 . In the limiting case when $R_2 = R_1$, $T_2 = T_1$, and $\Delta_2 = \Delta_1$.

39. Modifications of location. Some of these modifications may be solved by the methods used for simple curves. For example:

a. It is desired to move the tangent VB , Fig. 26, parallel to itself to $V'B'$. Run a new curve from the *P.C.C.* which shall reach the new tangent at B' , where the chord of the old curve

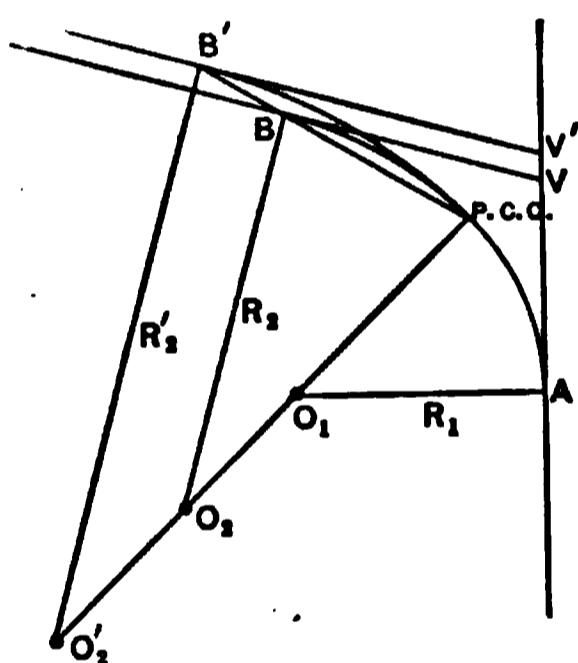


FIG. 26.

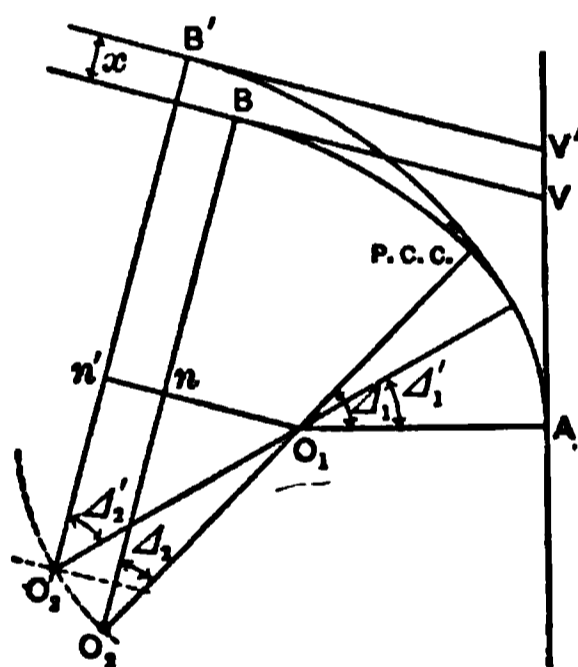


FIG. 27.

intersects the new tangent. The solution is almost identical with that in § 33, a.

b. Assume that it is desired to change the forward tangent (as above) but to retain the same radius. In Fig. 27

$$(R_2 - R_1) \cos \Delta_1 = O_1 n;$$

$$(R_2 - R_1) \cos \Delta_1' = O_1' n'.$$

$$x = O_1 n - O_1' n' = (R_2 - R_1)(\cos \Delta_1 - \cos \Delta_1').$$

$$\cos \Delta_1' = \cos \Delta_1 - \frac{x}{R_2 - R_1} \quad \cdot \quad \cdot \quad \cdot \quad (24)$$

The *P.C.C.* is moved *backward* along the sharper curve an angular distance of $\Delta_2' - \Delta_2 = \Delta_1 - \Delta_1'$.

In case the tangent is moved inward rather than outward, the solution will apply by transposing Δ_2 and Δ_2' . Then we will have

$$\cos \Delta_2' = \cos \Delta_2 + \frac{x}{R_2 - R_1} \quad \cdot \quad \cdot \quad \cdot \quad (25)$$

The *P.C.C.* is then moved *forward*.

c. Assume the same case as (b) except that the larger radius comes first and that the tangent adjacent to the smaller radius is moved. In Fig. 28

$$(R_2 - R_1) \cos \Delta_1 = O_1 n;$$

$$(R_2 - R_1) \cos \Delta_1' = O_1' n'.$$

$$x = O_1' n' - O_1 n = (R_2 - R_1)(\cos \Delta_1' - \cos \Delta_1).$$

$$\cos \Delta_1' = \cos \Delta_1 + \frac{x}{R_2 - R_1} \quad \cdot \quad \cdot \quad \cdot \quad (26)$$

The *P.C.C.* is moved *forward* along the easier curve an angular distance of $\Delta_1' - \Delta_1 = \Delta_2 - \Delta_2'$.

In case the tangent is moved *inward*, transpose as before and we have

$$\cos \Delta_1' = \cos \Delta_1 - \frac{x}{R_2 - R_1} \quad \cdot \quad \cdot \quad \cdot \quad (27)$$

The *P.C.C.* is moved *backward*.

d. Assume that the radius of one curve is to be altered without changing either tangent. Assume conditions as in Fig. 29. For the diagrammatic solution assume that R_2 is to be in-

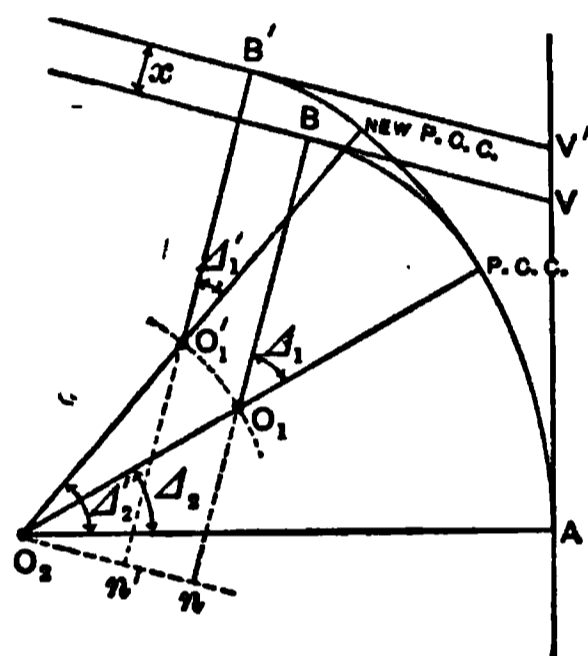


FIG. 28.

creased by O_1S . Then, since R_2' must pass through O_1 and extend beyond O_1 a distance O_1S , the locus of the new center must lie on the arc drawn about O_1 as center and with O_1S as

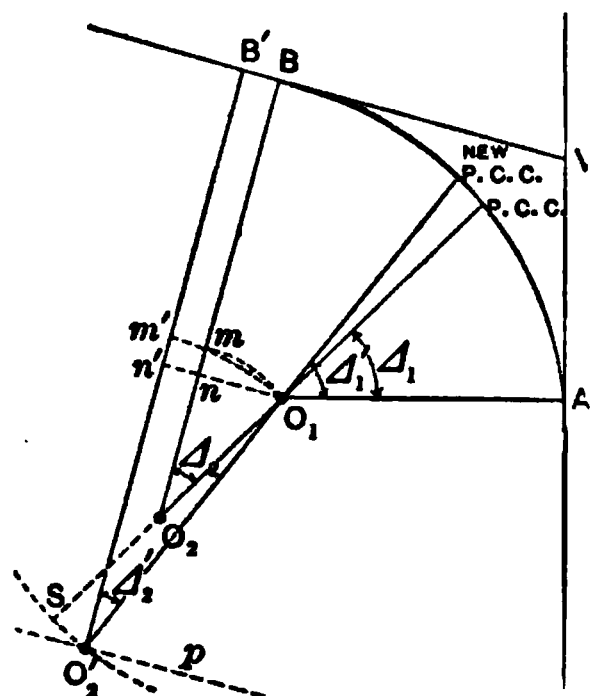


FIG. 29.

radius. The locus of O_2' is also given by a line $O_2'p$ parallel to BV and at a distance of R_2' (equal to $S \dots P.C.C.$) from it. The new center is therefore at the intersection O_2' . An arc with radius R_2' will therefore be tangent at B' and tangent to the old curve *produced* at NEW *P.C.C.* Draw O_1n' perpendicular to O_2B . With O_1 as center draw the arc O_1m , and with O_2' as center draw the arc O_2m' . $mB = m'B' = R_1$. $\therefore mn = m'n' =$

$$(R_2' - R_1) \text{ vers } \Delta_2' = (R_2 - R_1) \text{ vers } \Delta_2.$$

$$\therefore \text{vers } \Delta_2' = \frac{(R_2 - R_1)}{(R_2' - R_1)} \text{ vers } \Delta_2. \quad . \quad . \quad . \quad (28)$$

$$O_1n = (R_2 - R_1) \sin \Delta_2;$$

$$O_1n' = (R_2' - R_1) \sin \Delta_2'.$$

$$BB' = O_1n' - O_1n = (R_2' - R_1) \sin \Delta_2' - (R_2 - R_1) \sin \Delta_2. \quad (29)$$

This problem may be further modified by assuming that the radius of the curve is decreased rather than increased, or that the smaller radius follows the larger. The solution is similar and is suggested as a profitable exercise.

It might also be assumed that, instead of making a given change in the radius R_1 , a given change BB' is to be made. Δ_2' and R_2' are required. Eliminate R_2' from Eqs. 28 and 29 and solve the resulting equation for Δ_2' . Then determine R_2' by a suitable inversion of either Eq. 28 or 29.

As in §§ 32 and 33, the above problems are but a few, although perhaps the most common, of the problems the engineer may meet with in compound curves. All of the ordinary problems may be solved by these and similar methods.

40. Problems. *a.* Assume that the two tangents of a compound curve are to be 348 feet and 624 feet, and that $\Delta_1 = 22^\circ 16'$ and $\Delta_2 = 28^\circ 20'$. Required the radii.

[Ans, $R_1 = 326.92$; $R_2 = 1574.85$.]

b. A line crosses a valley by a compound curve which is first a 6° curve for $46^\circ 30'$ and then a $9^\circ 30'$ curve for $84^\circ 16'$. It is afterward decided that the last tangent should be 6 feet farther up the hill. What are the required changes? [Note. The second tangent is evidently moved *outward*. The solution corresponds to that in the first part of § 39, *c*. The *P.C.C.* is moved forward 16.39 feet. If it is desired to know how far the *P.T.* is moved in the direction of the tangent (i.e., the *projection* of BB' , Fig. 28, on $V'B'$), it may be found by observing that it is equal to $nn' = (R_2 - R_1)(\sin \Delta_1 - \sin \Delta_1')$. In this case it equals 0.65 foot, which is very small because Δ_1 is nearly 90° . The value of Δ_2 ($46^\circ 30'$) is not used, since the solution is independent of the value of Δ_2 . The student should learn to recognize which quantities are mutually related and therefore essential to a solution, and which are independent and non-essential.]

TRANSITION CURVES.

41. Superelevation of the outer rail on curves. When a mass is moved in a circular path it requires a centripetal force to keep it moving in that path. By the principles of mechanics we know that this force equals $Gv^2 \div gR$, in which G is the weight, v the velocity in feet per second, g the acceleration of gravity in feet per second in a second, and R the radius of curvature. If the two rails of a curved track were laid on a level (transversely), this centripetal force could only be furnished by the

pressure of the wheel-flanges against the rails. As this is very objectionable, the outer rail is elevated so that the reaction of the rails against the wheels shall contain

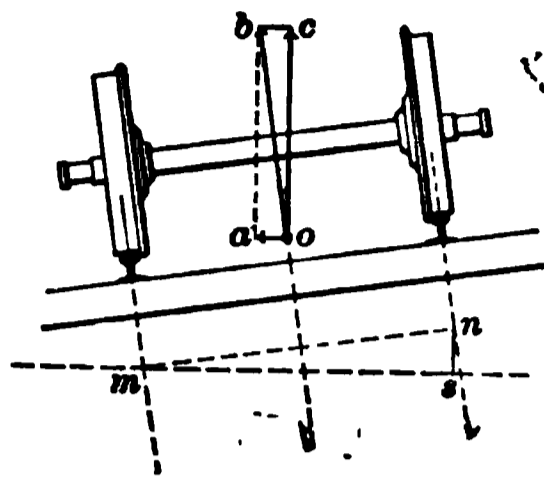


FIG. 30.

a horizontal component equal to the required centripetal force. In Fig. 30, if ob represents the reaction, oc will represent the weight G , and ao will represent the required centripetal force. From similar triangles we may write $sn:sm::ao:oc$. Call $g = 32.17$. Call $R = 5730 \div D$, which is sufficiently accurate

for this purpose (see § 19). Call $v = 5280V \div 3600$, in which V is the velocity in miles per hour. mn is the distance between rail centers, which, for an 80-lb. rail and standard gauge, is 4.916 feet. sm is slightly less than this. As an average value we may call it 4.900, which is its exact value when the superelevation is $4\frac{3}{4}$ inches. Calling $sn = e$, we have

$$e = sm \frac{ao}{oc} = 4.9 \frac{Gv^2}{gR} \frac{1}{G} = \frac{4.9 \times 5280^2 V^2 D}{32.17 \times 3600^2 \times 5730}.$$

$$e = .0000572 V^2 D. \quad . \quad . \quad . \quad . \quad . \quad (30)$$

It should be noticed that, according to this formula, the required superelevation varies as the *square* of the velocity, which means that a change of velocity of only 10% would call for a change of superelevation of 21%. Since the velocities of trains over any road are extremely variable, it is impossible to adopt any superelevation which will fit all velocities even approximately. The above fact also shows why any over-refinement in the calculations is useless and why the above approximations, which are really small, are amply justifiable. For example, the above formula contains the approximation that $R = 5730 \div D$. In the extreme case of a 10° curve the error involved would be about 1%. A change of about $\frac{1}{2}$ of 1% in

the velocity, or say from 40 to 40.2 miles per hour, would mean as much. The error in e due to the assumed constant value of sm is never more than a very small fraction of 1%. The rail-laying is not done closer than this. The following tabular form is based on Eq. 30:

SUPERELEVATION OF THE OUTER RAIL (IN FEET) FOR VARIOUS VELOCITIES AND DEGREES OF CURVATURE.

Velocity in Miles per Hour.	Degree of Curve.									
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
30	.05	.10	.15	.20	.26	.31	.36	.41	.46	.51
40	.09	.18	.27	.37	.46	.55	.64	.73	.82	
50	.14	.29	.43	.57	.71	.86				
60	.20	.41	.62	.82						

42. Practical rules for superelevation. A much used rule for superelevation is to “elevate one half an inch for each degree of curvature.” The rule is rational in that e in Eq. 30 varies directly as D . The above rule therefore agrees with Eq. 30 when V is about 27 miles per hour. However applicable the rule may have been in the days of low velocities, the elevation thus computed is too small now.

Another (and better) rule is to “elevate for the speed of the fastest trains.” This rule is further justified by the fact that a four-wheeled truck, having two parallel axles, will always tend to run to the outer rail and will require considerable flange pressure to guide it along the curve. The effect of an excess of superelevation on the slower trains will only be to relieve this flange pressure somewhat. This rule is coupled with the limitation that the elevation should never exceed a limit of six inches—sometimes eight inches. This limitation implies that locomotive engineers must reduce the speed of fast trains around sharp curves until the speed does not exceed that for which the actual superelevation used is suitable. The heavy line in the tabular form (§ 41) shows the six-inch limitation.

Some roads furnish their track foremen with a list of the superelevations to be used on each curve in their sections. This method has the advantage that each location may be separately studied, and the proper velocity, as affected by local conditions (*e.g.*, proximity to a stopping-place for all trains), may be determined and applied.

Another method is to allow the foremen to determine the superelevation for each curve by a simple measurement taken at the curve. The rule is developed as follows: By an inversion of Eq. 19 we have

$$x = chord^2 \div 8R \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Putting x equal to e in Eq. 30 and solving for “*chord*,” we have

$$\begin{aligned} chord^2 &= .0000572 V^2 D 8R \\ &= 2.621 V^2. \\ chord &= 1.62 V. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32) \end{aligned}$$

To apply the rule, assume that 50 miles per hour is fixed as the velocity from which the superelevation is to be computed. Then $1.62 V = 1.62 \times 50 = 81$ feet, which is the distance given to the trackmen. Stretch a tape (or even a string) with a length of 81 feet between two points on the inside head of the outer rail or the outer head of the inner rail. The ordinate at the middle point then equals the superelevation. The values of this chord length for varying velocities are given in the accompanying tabular form.

Velocity in miles per hour.....	20	25	30	35	40	45	50	55	60
Chord length in feet	32.4	40.5	48.6	56.7	64.8	72.9	81.0	89.1	97.2

43. Transition from level to inclined track. On curves the track is inclined transversely; on tangents it is level. The transition from one condition to the other must be made gradu-

ally. If there is no transition curve, there must be either inclined track on the tangent or insufficiently inclined track on the curve or both. Sometimes the full superelevation is continued through the total length of the curve and the "run-off" (having a length of 100 to 200 feet) is located entirely on the tangents at each end. In other practice it is located partly on the tangent and partly on the curve. Whatever the method, the superelevation is correct at only one point of the run-off. At all other points it is too great or too small. This (and other causes) produces objectionable lurches and resistances when entering and leaving curves. The object of transition curves is to obviate these resistances.

44. Fundamental principle of transition curves. If a curve has variable curvature, beginning at the tangent with a curve of infinite radius, and the curvature gradually sharpens until it equals the curvature of the required simple curve and there becomes tangent to it, the superelevation of such a transition curve may begin at zero at the tangent, gradually increase to the required superelevation for the simple curve, and yet have at every point the superelevation required by the curvature at that point. Since in Eq. (30) e is directly proportional to D , the required curve must be one in which the degree of curve increases directly as the distance along the curve. The mathematical development of such a curve is quite complicated. It has, however, been developed, and tables have been computed for its use, by Prof. C. L. Crandall. The following method has the advantage of great simplicity, while its agreement with the true transition curve is as close as need be, as will be shown.

45. Multiform compound curves. If the transition curve commences with a very flat curve and at regular even chord lengths compounds into a curve of sharper curvature until the desired curvature is reached, the increase in curvature at each chord point being uniform, it is plain that such a curve is a close approximation to the true spiral, especially since the rails as laid will *gradually* change their curvature rather than maintain a uniform curvature throughout each chord length and

then abruptly change the curvature at the chord points. Such a curve, *as actually laid*, will be a much closer approximation to the true curve than the multiform compound curve by which it is set out. There will actually be a *gradual* increase in curvature which increases directly as the length of the curve.

46. Required length of spiral. The required length of spiral evidently depends on the amount of superelevation to be gained, and also depends somewhat on the speed. If the spiral is laid off in 25-foot chord lengths, with the first chord subtending a 1° curve, the second a 2° curve, etc., the fifth chord will subtend a 5° curve, and the increase from this last chord to a 6° curve is the same as the uniform increase of curvature between the chords. The same spiral extended would run on to a 12° curve in $(12 - 1)25 = 275$ feet. The last chord of a spiral should have a smaller degree of curvature than the simple curve to which it is joined. If the curves are very sharp, such as are used in street work and even in suburban trolley work, an increase in degree of curvature of 1° per 25 feet will not be sufficiently rapid, as such a rate would require too long curves. 2° , 10° , or even 20° increase per 25 feet may be necessary, but then the chords should be reduced to 5 feet. Such a rapid rate of increase is justified by the necessary reduction in speed. On the other hand, very high speed will make a lower rate of increase desirable, and therefore a spiral whose degree of curvature increases only $0^\circ 30'$ per 25 feet may be used. Such a spiral would require a length of 375 feet to run on to an 8° curve, which is inconveniently long, but it might be used to run on to a 4° curve, where its length would be only 175 feet. Three spirals have been developed in Table IV, each with chords of 25 feet, the rate of increase in the degree of curvature being $0^\circ 30'$, 1° and 2° per chord. One of these will be suitable for any curvature found on ordinary steam-railroads.

47. To find the ordinates of a 1° -per-25-feet spiral. Since the first chord subtends a 1° curve, its central angle is $0^\circ 15'$ and the angle aQV (Fig. 31) is $7' 30''$. The tangent at a makes an angle of $15'$ with VQ . The angle between the chord ba and

the tangent at a is $\frac{1}{2}(30') = 15'$, and the angle $bab'' = \frac{1}{2}(30') + 15' = 30'$. Similarly the angle $cbc' = \frac{1}{2}(45') + 30' + 15' = 67' 30' = 1^\circ 07' 30''$, and the angle dcd'' is $2^\circ 0'$. The ordinate $aa' = 25 \sin 7' 30''$, and $Qa' = 25 \cos 7' 30''$. $Qb' = Qa' + a'b' = Qa' + ab'' = 25 (\cos 7' 30'' + \cos 30')$. $bb' = b'b'' + bb'' = 25 (\sin 7' 30'' + \sin 30')$. Similarly the ordinates of c, d , etc., may be obtained.

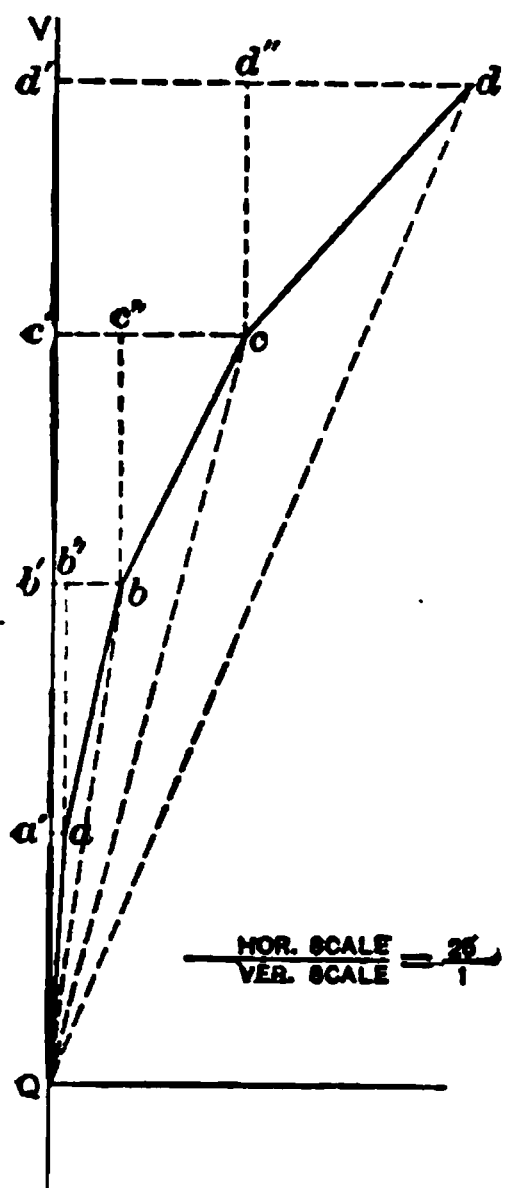


FIG. 31.

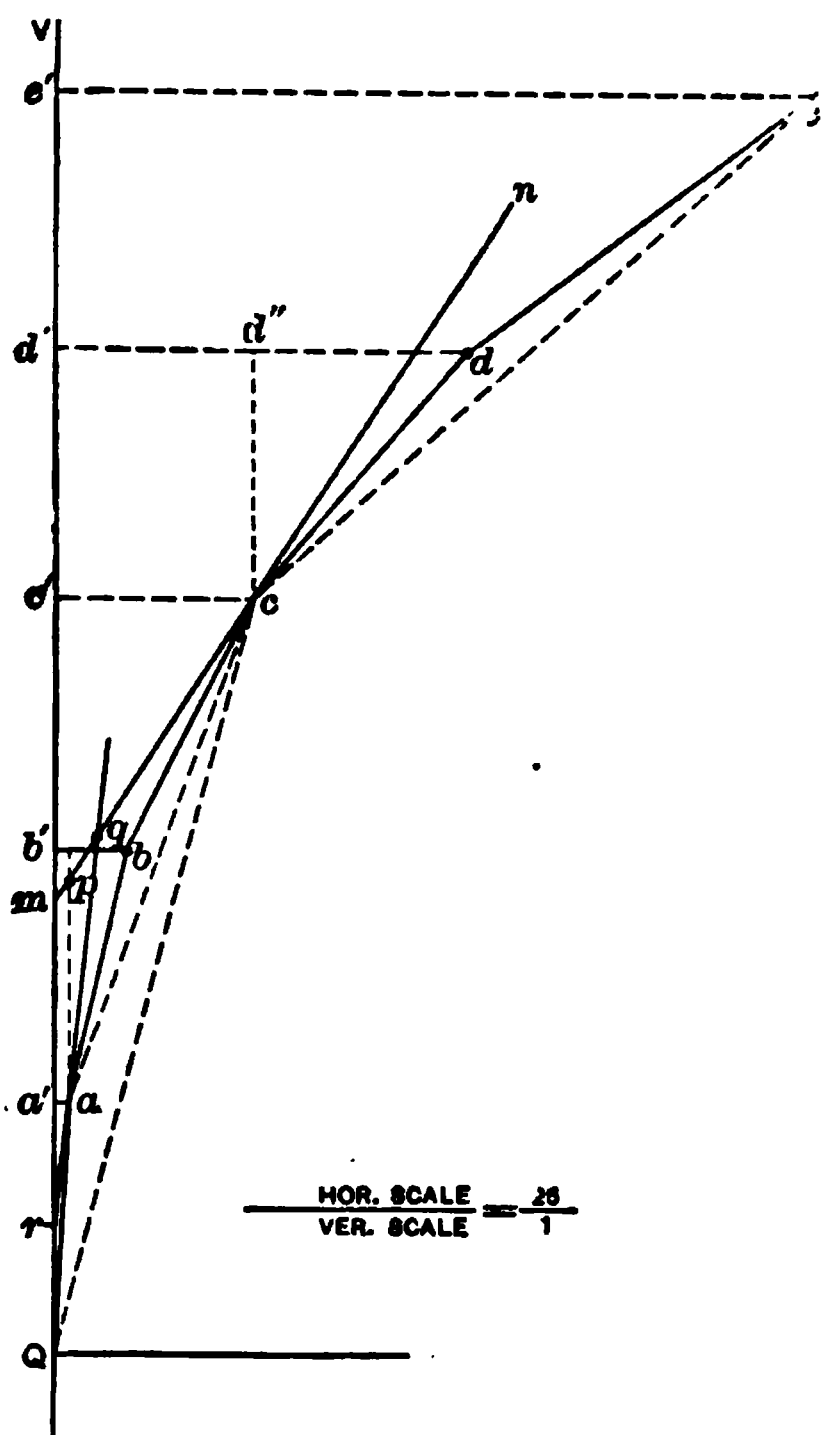


FIG. 32.

48. To find the deflections from any point of the spiral. $aQV = 7' 30''$. $\tan bQV = bb' \div Qb'$; $\tan cQV = cc' \div Qc'$; etc. Thus we are enabled to find the deflection angles from the tangent at Q to any point of the spiral.

The tangent to the curve at c (Fig. 32) makes an angle of $1^\circ 30'$ with QV , or $cmV = 1^\circ 30'$. $Qcm = cmV - cQm$. The

49. Connection of spiral with circular curve and with tangent. See Fig. 33.* Let AV and BV be the tangents to be connected by a D° curve, having a suitable spiral at each end. If no spirals were to be used, the problem would be solved as in simple curves giving the curve AMB . Introducing the spiral has the effect of throwing the curve away from the vertex a distance MM' and reducing the central angle of the D° curve by 2ϕ . Continuing the curve beyond Z and Z' to A' and B' , we will have $AA' = BB' = MM'$. ZK = the x ordinate and is therefore known. Call $MM' = m$. $A'N = x - R \text{ vers } \phi$. Then

$$m = MM' = AA' = \frac{A'N}{\cos \frac{1}{2}\Delta} = \frac{x - R \text{ vers } \phi}{\cos \frac{1}{2}\Delta}. \quad (33)$$

$$NA = AA' \sin \frac{1}{2}\Delta = (x - R \text{ vers } \phi) \tan \frac{1}{2}\Delta.$$

$$\begin{aligned} VQ &= QK - KN + NA + AV \\ &= y - R \sin \phi + (x - R \text{ vers } \phi) \tan \frac{1}{2}\Delta + R \tan \frac{1}{2}\Delta \\ &= y - R \sin \phi + x \tan \frac{1}{2}\Delta + R \cos \phi \tan \frac{1}{2}\Delta. \end{aligned} \quad (34)$$

When $A'N$ has already been computed, it may be more convenient to write

$$VQ = y + R (\tan \frac{1}{2}\Delta - \sin \phi) + A'N \tan \frac{1}{2}\Delta. \quad (35)$$

$$\begin{aligned} VM' &= VM + MM' \\ &= R \text{ exsec } \frac{1}{2}\Delta + \frac{x}{\cos \frac{1}{2}\Delta} - \frac{R \text{ vers } \phi}{\cos \frac{1}{2}\Delta}. \end{aligned} \quad (36)$$

$$\begin{aligned} AQ &= VQ - AV \\ &= y - R \sin \phi + (x - R \text{ vers } \phi) \tan \frac{1}{2}\Delta. \end{aligned} \quad (37)$$

Example. To join two tangents making an angle of $34^\circ 20'$ by a $5^\circ 40'$ curve and suitable spirals. Use 1° -per-25-feet

* The student should at once appreciate the fact of the necessary distortion of the figure. The distance MM' in Fig. 33 is perhaps 100 times its real proportional value.

spirals with five chords. Then $\phi = 3^\circ 45'$, $x = 2.999$, $\frac{1}{2}\Delta = 17^\circ 10'$, and $y = 124.942$.

(Eq. 33)		R	3.00497
		vers ϕ	7.33063
	2.166		<u>0.33560</u>
	$x = 2.999$		
	$A'N = 0.833$		9.92064
		$\cos \frac{1}{2}\Delta$	9.98021
	$m = MM' = AA' = 0.872$		<u>9.94043</u>
(Eq. 36)		R	3.00497
		exsec $\frac{1}{2}\Delta$	8.66863
	$VM = 47.164$		<u>1.67360</u>
	$m = 0.872$		
	$VM' = 48.036$		
(Eq. 35)	$y = 124.942$	nat. tan $\frac{1}{2}\Delta = .30891$	
		nat. sin $\phi = .06540$	
		<u>.24351</u>	9.38651
		R	3.00497
	246.314		<u>2.39148</u>
	[See above]	$A'N$	9.92064
		$\tan \frac{1}{2}\Delta$	9.48984
	0.257	AN	<u>9.41048</u>
	$VQ = 371.513$		
(Eq. 37)		R	3.00497
		$\tan \frac{1}{2}\Delta$	9.48984
	312.471	AV	<u>2.49481</u>
	$AQ = 59.042$		

50. Field-work. When the spiral is designed during the original location, the tangent distance VQ should be computed and the point Q located. It is hardly necessary to locate all of the points of the spiral until the track is to be laid. The extremities should be located, and as there will usually be one and perhaps two full station points on the spiral, these should

also be located. Z may be located by setting off $QK = y$ and $KZ = x$, or else by the tabular deflection for Z from Q and the distance ZQ , which is the long chord. Setting up the instrument at Z and sighting back at Q with the proper deflection, the tangent at Z may be found and the circular curve located as usual, its central angle being $\Delta - 2\phi$. A similar operation will locate Q' from Z' .

To locate points on the spiral. Set up at Q , with the plates reading 0° when the telescope sights along VQ . Set off from Q the deflections given in Table IV for the instrument at Q , using a chord length of 25 feet, the process being like the method for simple curves except that the deflections are irregular. If a full station-point occurs within the spiral, interpolate between the deflections for the adjacent spiral-points. For example, a spiral begins at Sta. $56 + 15$. Sta. 57 comes 10 feet beyond the third spiral point. The deflection for the third point is $35' 0''$; for the fourth it is $56' 15''$. $\frac{10}{25}$ of the difference ($21' 15''$) is $8' 30''$; the deflection for Sta. 57 is therefore $43' 30''$. This method is not theoretically accurate, but the error is small. Arriving at z , the forward alignment may be obtained by sighting back at Q (or at any other point) with the given deflection for that point from the station occupied. Then when the plates read 0° the telescope will be tangent to the spiral and to the succeeding curve. All rear points should be checked from z . If it is necessary to occupy an intermediate station, use the deflections given for that station, orienting as just explained for z , checking the back points and locating all forward points up to z if possible.

After the center curve has been located and z' is reached, the other spiral must be located but *in reverse order*, i.e., the sharp curvature of the spiral is at z' and the curvature decreases toward Q' .

51. To replace a simple curve by a curve with spirals. This may be done by the method of § 49, but it involves shifting the whole track a distance m , which in the given example equals 0.87 foot. Besides this the track is appreciably shortened,

which would require rail-cutting. But the track may be kept at practically the same length and the lateral deviation from the old track may be made very small by slightly sharpening the curvature of the old track, moving the new curve so that it is wholly or partially *outside* of the old curve, the remainder of it with the spirals being *inside* of the old curve. It is found by experience that a decrease in radius of from 1% to 5% will answer

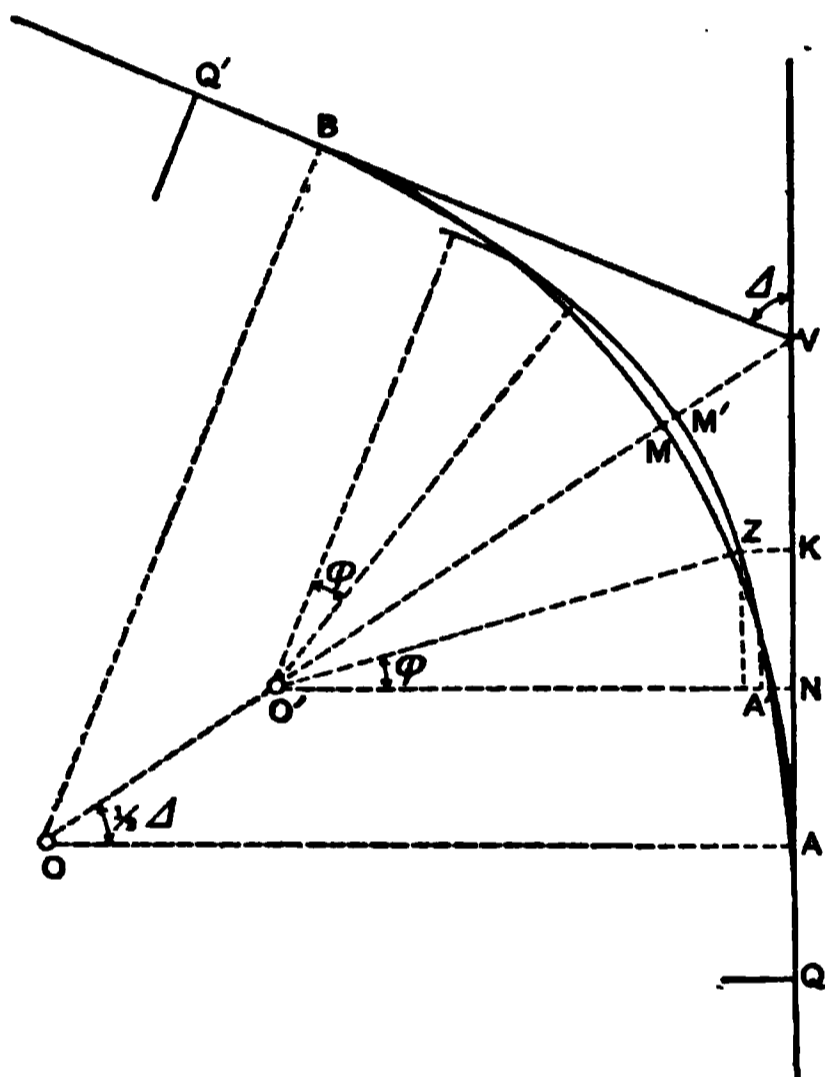


FIG. 34.

the purpose. The larger the central angle the less the change. The solution is as indicated in Fig. 34.

$$O'N = R' \cos \phi + x.$$

$$O'V = O'N \sec \frac{1}{2}\Delta.$$

$$= R' \cos \phi \sec \frac{1}{2}\Delta + x \sec \frac{1}{2}\Delta.$$

$$m = MM' = MV - M'V$$

$$= R \operatorname{exsec} \frac{1}{2}\Delta - (O'V - R')$$

$$= R \operatorname{exsec} \frac{1}{2}\Delta - R' \cos \phi \sec \frac{1}{2}\Delta - x \sec \frac{1}{2}\Delta + R'. \quad (38)$$

$$AQ = QK - KN + NV - VA$$

$$= y - R' \sin \phi + (R' \cos \phi + x) \tan \frac{1}{2}\Delta - R \tan \frac{1}{2}\Delta$$

$$= y - R' \sin \phi + R' \cos \phi \tan \frac{1}{2}\Delta - (R - x) \tan \frac{1}{2}\Delta. \quad (39)$$

The length of the old curve from Q to $Q' = 2AQ + 100\frac{\Delta}{D}$.

The length of the new curve from Q to $Q' = 2L + 100\frac{\Delta - 2\phi}{D'}$,
in which L is the length of each spiral.

Example. Suppose the old curve is a $7^\circ 30'$ curve with a central angle of $38^\circ 40'$. As a trial, compute the relative length of a new 8° curve with spirals of seven chords. $\phi = 7^\circ 0'$; $\frac{1}{2}\Delta = 19^\circ 20'$; R (for the $7^\circ 30'$ curve) = 764.489; R' (for the 8° curve) = 716.779; $x = 7.628$.

[Eq. 38]

	R exsec $\frac{1}{2}\Delta$	2.88387 8.77642 <hr/> 1.65979 <hr/> <hr/> 2.85588 9.99675 0.02521 <hr/> 2.87734 <hr/> <hr/> 0.88241 0.02521 <hr/> 0.90762 <hr/> <hr/>
$R' = \frac{45.687}{716.779}$ <hr/> 762.466		
	R' cos ϕ sec $\frac{1}{2}\Delta$	
	x sec $\frac{1}{2}\Delta$	
	8.084 <hr/> 762.037	
$m = \frac{762.037}{0.429}$ <hr/> <hr/> 174.722		
	R' sin ϕ	2.85588 9.08589 <hr/> 1.94128 <hr/> <hr/> 2.85588 9.99675 9.54512 <hr/> 2.89723 <hr/> <hr/>
	$R = 764.489$ $x = 7.628$	
	756.861 tan $\frac{1}{2}\Delta$	2.87901 9.54512 <hr/> 2.42413 <hr/> <hr/>
	265.543 <hr/> 852.896	
$AQ = \frac{424.828}{852.896}$ <hr/> <hr/> 71.482		

[Eq. 39]

The length of the old curve from Q to Q' is

$$\begin{array}{rcl}
 100 \frac{\Delta}{D} = 100 \frac{38.667}{7.5} = & & 515.556 \\
 2\Delta Q = 2 \times 71.433 = & & 142.864 \\
 \hline
 & & 658.420 \\
 \text{New curve: } 100 \frac{\Delta - 2\phi}{D'} = 100 \frac{38.667 - 14.000}{8.0} = 308.333 & & \\
 2L = 2 \times 175 = 350.000 & & \\
 \hline
 & 658.333 & 658.333 \\
 \text{Difference in length} = & & 0.087
 \end{array}$$

Considering that this difference may be divided among 22 joints (using 30-foot rails) no rail-cutting would be necessary. If the difference is too large, a slight variation in the value of the new radius R' will reduce the difference as much as necessary. A truer comparison of the lengths would be found by comparing the lengths of the arcs.

52. Application of transition curves to compound curves. Since compound curves are only employed when the location is limited by local conditions, the elements of the compound curve should be determined (as in §§ 38 and 39) regardless of the transition curves, depending on the fact that the lateral shifting of the curve when transition curves are introduced is very small. If the limitations are very close, an estimated allowance may be made for them.

Methods have been devised for inserting transition curves between the branches of a compound curve, but the device is complicated and usually needless, since when the train is once on a curve the wheels press against the outer rail steadily and a change in curvature will not produce a serious jar even though the superelevation is temporarily a little more or less than it should be.

If the easier curve of the compound curve is less than 3° or 4° , there may be no need for a transition curve off from that branch. This problem then has two cases according as transition curves are used at both ends or at one end only.

a. *With transition curves at both ends.* Adopting the method of § 49, calling $\Delta_1 = \frac{1}{2}\Delta$, we may compute $m_1 = MM_1'$. Similarly, calling $\Delta_2 = \frac{1}{2}\Delta$, we may compute $m_2 = MM_2'$. But

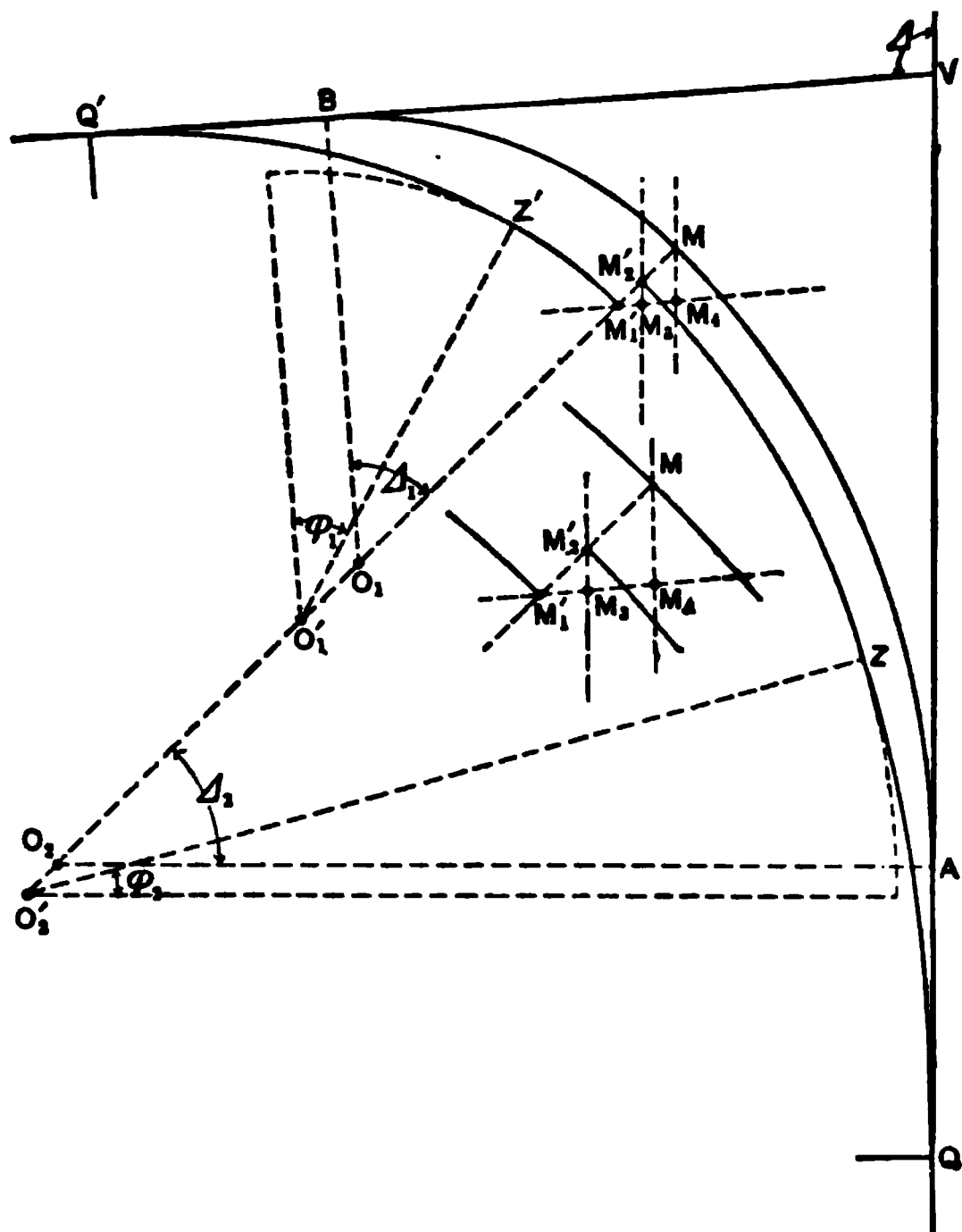


FIG. 35.

M_1' and M_2' must be made to coincide. This may be done by moving the curve $Z'M_1'$ and its transition curve parallel to $Q'V$ a distance $M_1'M_2$, and the other curve parallel to QV a distance $M_2'M_1$. In the triangle $M_1'M_2M_3$, the angle at $M_1' = 90^\circ - \Delta_1$, the angle at $M_2' = 90^\circ - \Delta_2$, and the angle at $M_3 = \Delta$.

$$\left. \begin{aligned} \text{Then } M_1'M_2 &= M_1'M_3 \frac{\sin(90^\circ - \Delta_2)}{\sin \Delta} = (m_1 - m_2) \frac{\cos \Delta_2}{\sin \Delta} \\ \text{Similarly } M_2'M_1 &= M_2'M_3 \frac{\sin(90^\circ - \Delta_1)}{\sin \Delta} = (m_2 - m_1) \frac{\cos \Delta_1}{\sin \Delta} \end{aligned} \right\} (40)$$

b. *With a transition curve on the sharper curve only.* Compute $m_1 = MM_1'$ as before; then move the curve Z_1M_1' parallel to $Q'V$ a distance of

$$M_1'M_1 = m_1 \frac{\cos \Delta_1}{\sin \Delta_1} \quad . \quad . \quad . \quad . \quad . \quad (41)$$

The simple curve MA is moved parallel to VA a distance of

$$MM_1 = m_1 \frac{\cos \Delta_1}{\sin \Delta_1} \quad . \quad . \quad . \quad . \quad . \quad (42)$$

If Δ_1 and Δ_2 are both small, $M_1'M_1$ and MM_1 may be more than m_1 , but the lateral deviation of the new curve from the old will always be less than m_1 .

53. To replace a compound curve by a curve with spirals. The solution is somewhat analogous to that of § 51. Compute m_1 for the sharper branch of the curve, placing $\Delta_1 = \frac{1}{2}\Delta$ in Eq. 38. Since m_1 and m_2 for the two branches of the curve must be identical, a value for R_1' must be found which will satisfy the determined value of $m_2 = m_1$. Solving Eq. 38 for R' , we obtain

$$R' = \frac{R \text{ vers } \frac{1}{2}\Delta - m \cos \frac{1}{2}\Delta - x}{\cos \phi - \cos \frac{1}{2}\Delta} \quad . \quad . \quad . \quad . \quad (43)$$

Substituting in this equation the known value of $m_1 (= m_2)$ and calling $R' = R_1'$, $R = R_2$, and $\Delta_1 = \frac{1}{2}\Delta$, solve for R_1' . Obtain the value of AQ for each branch of the curve separately by Eq. 39, and compare the lengths of the old and new lines.

Example. Assume a compound curve with $D_1 = 8^\circ$; $D_2 = 4^\circ$; $\Delta_1 = 36^\circ$ and $\Delta_2 = 32^\circ$. Use 1° -per-25-feet spirals; $\phi_1 = 7^\circ 0'$; $\phi_2 = 1^\circ 30'$. Assume that the sharper curve is sharpened from $8^\circ 0'$ to $8^\circ 12'$.

[Eq. 38]

$$R_1' = \frac{169.209}{699.326} \\ \hline 868.535$$

$$857.970$$

$$m_1 = \frac{867.399}{1.136}$$

[Eq. 43]

$$217.700$$

$$\frac{1.726}{215.974}$$

$$x_2 = \frac{0.963}{0.763} \\ \hline 1.726$$

$$\text{nat. cos } \phi = .99966 \\ \text{nat. cos } \Delta_2 = .84805$$

$$\hline .15161$$

$$R_2' = 1424.54$$

$$[4^\circ 1' 22'']$$

[Eq. 39]

$$y_1 = 174.722$$

$$85.226$$

$$504.802$$

$$AQ_1 = \frac{679.024}{600.461} \\ \hline 78.563$$

$$\frac{515.235}{600.461}$$

$$R_1 \\ \text{exsec } 36^\circ \quad \begin{array}{r} 2.85538 \\ 9.87303 \end{array}$$

$$\hline 2.22842$$

$$R_1' \\ \text{cos } \phi_1 \\ \text{sec } \Delta_1 \quad \begin{array}{r} 2.84468 \\ 9.99675 \\ 0.09204 \end{array}$$

$$\hline 2.93347$$

$$x_1 \\ \text{sec } \Delta_1 \quad \begin{array}{r} 0.88241 \\ 0.09204 \end{array}$$

$$\hline 0.97445$$

$$R_2 \\ \text{vers } 32^\circ \quad \begin{array}{r} 3.15615 \\ 9.18176 \end{array}$$

$$\hline 2.33785$$

$$m_1 = 1.136 \\ \text{cos } 32^\circ \quad \begin{array}{r} 0.05538 \\ 9.92842 \end{array}$$

$$\hline 9.98380$$

$$\hline 2.38440$$

$$\hline 9.18073$$

$$\hline 3.15367$$

$$R_1' \\ \text{sin } \phi_1 \quad \begin{array}{r} 2.84468 \\ 9.08586 \end{array}$$

$$\hline 1.93057$$

$$R_1' \\ \text{cos } \phi_1 \\ \tan \frac{1}{2} \Delta [\Delta_1 = 36^\circ] \quad \begin{array}{r} 2.84468 \\ 9.99675 \\ 9.86126 \end{array}$$

$$\hline 2.70269$$

$$R_1 = 716.779 \\ x_1 = 7.628$$

$$\hline 709.151 \\ \tan \frac{1}{2} \Delta \quad \begin{array}{r} 2.85074 \\ 9.86126 \end{array}$$

$$\hline 2.71206$$

[Eq. 39]

$$y_1 = 74.994$$

$$37\ 290$$

$$889.848$$

$$AQ_1 = 32.777$$

$$\begin{array}{r} R_1' \\ \sin \phi_1 \end{array} \quad \begin{array}{r} 8.15867 \\ 8.41792 \end{array}$$

$$\underline{\underline{1.57156}}$$

$$\begin{array}{r} R_1' \\ \cos \phi_1 \end{array} \quad \begin{array}{r} 8.15867 \\ 9.99985 \end{array}$$

$$\tan \frac{1}{2} \Delta (\Delta_1 = 82^\circ) \quad 9.79579$$

$$\underline{\underline{2.94931}}$$

$$R_1 = 1432.69$$

$$x_1 = 0.76$$

$$1431.93 \quad 8.15592$$

$$\tan \frac{1}{2} \Delta \quad 9.79579$$

$$\underline{\underline{2.95171}}$$

$$894.770$$

$$964.837$$

$$932.060$$

$$932.060$$

For the length of the old track we have:

$$100 \frac{\Delta_1}{D_1} = 100 \frac{36^\circ}{8^\circ} = 450.$$

$$100 \frac{\Delta_2}{D_2} = 100 \frac{32^\circ}{4^\circ} = 800.$$

$$AQ_1 = 78.563$$

$$AQ_2 = 32.777$$

$$\underline{\underline{1361.340}}$$

For the length of the new track we have:

$$100 \frac{\Delta_1 - \phi_1}{D_1'} = 100 \frac{29^\circ}{8^\circ.20} = 353.659$$

$$100 \frac{\Delta_2 - \phi_2}{D_2'} = 100 \frac{30^\circ.5}{4^\circ.023} = 758.140$$

$$\text{Spiral on } 8^\circ 12' \text{ curve} \quad 175.000$$

$$\text{" " } 4^\circ 01' 22' \text{ " } \quad 75.$$

$$\text{Length of new track} = \underline{\underline{1361.799}}$$

$$\text{" " old " } = \underline{\underline{1361.340}}$$

$$\text{Excess in length of new track} = 0.459 \text{ feet.}$$

Since the new track is slightly longer than the old, it shows that the new track runs too far *outside* the old track at the *P.C.C.* On the other hand the offset m is only 1.136. The maximum amount by which the new track comes *inside* of the old track at two points, presumably not far from Z' and Z , is very difficult to determine exactly. Since it is desirable that the maximum offsets (inside and outside) should be made as nearly equal as possible, this feature should not be sacrificed to an effort to make the two lines of precisely equal length so that the rails need not be cut. Therefore, if it is found that the offsets inside the old track are nearly equal to m (1.136), the above figures should stand. Otherwise m may be diminished (and the above excess in length of track diminished) by *increasing* R_1' very slightly and making the necessary consequent changes.

VERTICAL CURVES.

54. Necessity for their use. Whenever there is a change in the rate of grade, it is necessary to eliminate the angle that would be formed at the point of change and to connect the two grades by a curve. This is especially necessary at a sag between two grades, since the shock caused by abruptly forcing an upward motion to a rapidly moving heavy train is very severe both to the track and to the rolling stock.

55. Required length. Theoretically the length should depend on the change in the rate of grade, the greater change requiring a longer curve. The importance of this was greater in the days when link couplers were in universal use and the "slack" in a long train was very great. Under such circumstances, when a train was moving down a heavy grade the cars would crowd ahead against the engine. Reaching the sag, the engine would begin to pull out, rapidly taking out the slack. Six inches of slack on each car would amount to several feet on a long train, and the resulting jerk on the couplers, especially those near the rear of the train, has frequently resulted in

$\frac{1}{2}(163.4 + 163.8) = 163.6$; h , $\frac{1}{2}(163.6 + 162.6) = 163.1$. Then $eh = 0.5$. The elevations of the points on the curve are:

Sta. 15 + 20,	(A)	163.4
“ 16	, $163.4 - (.80 \times 0.8) + (.80^2 \times 0.5) =$	163.08
“ 17	, $162.6 + (.80 \times 1.2) + (.20^2 \times 0.5) =$	163.58
“ 17 + 20,	(C)	163.8

A theoretical inaccuracy in the above method lies in the fact that eh and all parallel lines are not truly vertical. In the above case the variation from the vertical is $0^\circ 07'$, while the effect of this variation on the elevations in this case (as in the most extreme cases) is absolutely inappreciable. The grades in the figure are necessarily very greatly exaggerated, which increases the apparent inaccuracy.

CHAPTER III.

EARTHWORK.

FORM OF EXCAVATIONS AND EMBANKMENTS.

58. Usual form of cross-section in cut or fill. The normal form of cross-section in cut is as shown in Fig. 37, in which $e . . . g$ represents the natural surface of the ground, no matter how irregular; ab represents the position and width of the re-

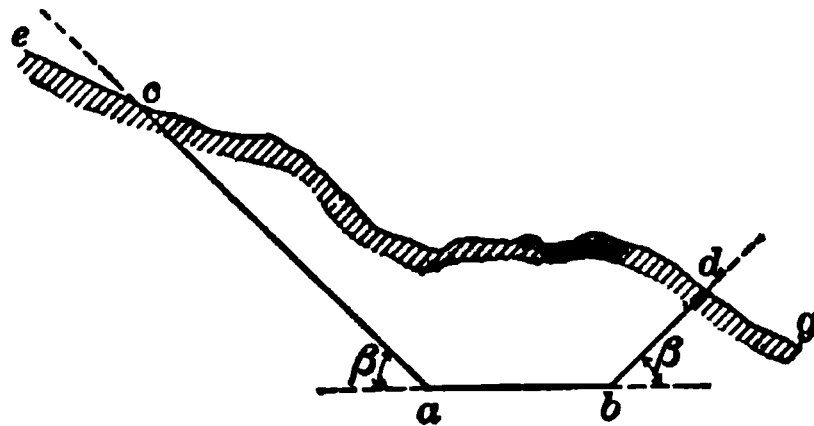


FIG. 37.

quired roadbed; ac and bd represent the "side slopes" which begin at a and b and which intersect the natural surface at such

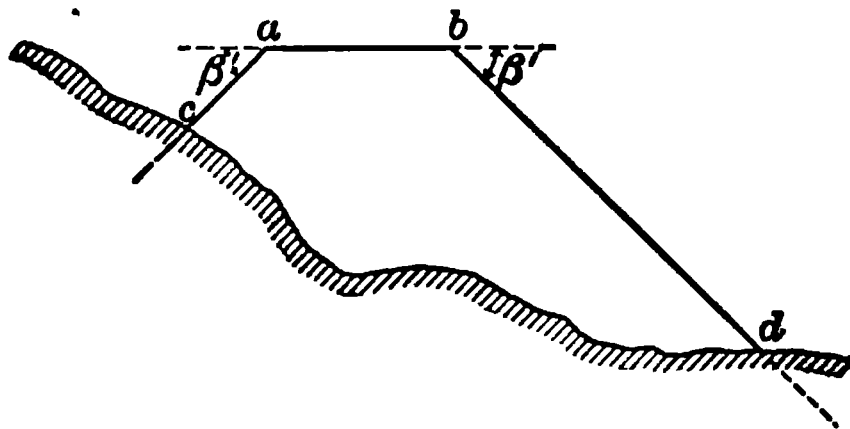


FIG. 38.

points (c and d) as will be determined by the required slope angle (β).

The normal section in fill is as shown in Fig. 38. The points c and d are likewise determined by the intersection of the required side slopes with the natural surface. In case the required roadbed (ab in Fig. 39) intersects the natural surface, both cut

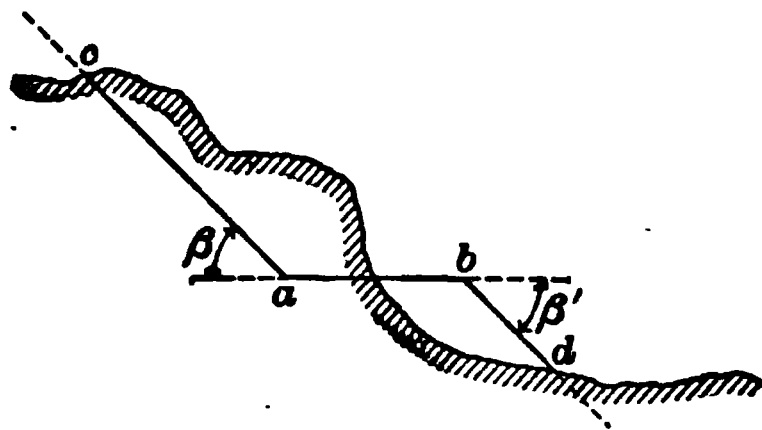


FIG. 39.

and fill are required, and the points c and d are determined as before. Note that β and β' are not necessarily equal. Their proper values will be discussed later.

59. Terminal pyramids and wedges. Fig. 40 illustrates the general form of cross-sections when there is a transition from cut to fill. $a \dots g$ represents the grade line of the road which passes from cut to fill at d . sdt represents the surface profile. A cross-section taken at the point where either side of the roadbed *first* cuts the surface (the point m in this case) will usually be triangular if the ground is regular. A similar cross-section should be taken at o , where the other side of the roadbed cuts the surface. In general the earthwork of cut and fill terminates in two pyramids. In Fig. 40 the pyramid vertices are at n and k , and the bases are lhm and opq . The roadbed is generally wider in cut than in fill, and therefore the section lhm and the altitude ln are generally greater than the section opq and the altitude pk . When the line of intersection of the roadbed and natural surface ($nodkm$) becomes perpendicular to the axis of the roadbed (ag) the pyramids become wedges whose bases are the nearest convenient cross-sections.

60. Slopes. a. Cuttings. The required slopes for cuttings vary from perpendicular cuts, which may be used in hard rock which will not disintegrate by exposure, to a slope of perhaps

4 horizontal to 1 vertical in a soft material like quicksand or in a clayey soil which flows easily when saturated. For earthy materials a slope of 1 : 1 is the maximum allowable, and even this should only be used for firm material not easily affected by



FIG. 40.

saturation. A slope of $1\frac{1}{2}$ horizontal to 1 vertical is a safer slope for average earthwork. It is a frequent blunder that slopes in cuts are made too steep, and it results in excessive work in clearing out from the ditches the material that slides down, at a much higher cost per yard than it would have cost to take it out at first, to say nothing of the danger of accidents from possible landslides.

b. Embankments. The slopes of an embankment vary from 1 : 1 to 1.5 : 1. A rock fill will stand at 1 : 1, and if some care is taken to form the larger pieces on the outside into a rough dry wall, a much steeper slope can be allowed. This method is sometimes a necessity in steep side-hill work. Earthwork embankments generally require a slope of $1\frac{1}{2}$ to 1. If made steeper at first, it generally results in the edges giving way, requiring repairs until the ultimate slope is nearly or quite $1\frac{1}{2}$: 1. The difficulty of incorporating the added material with the old embankment and preventing its sliding off frequently makes these repairs disproportionately costly.

61. Compound sections. When the cut consists partly of earth and partly of rock, a compound cross-section must be

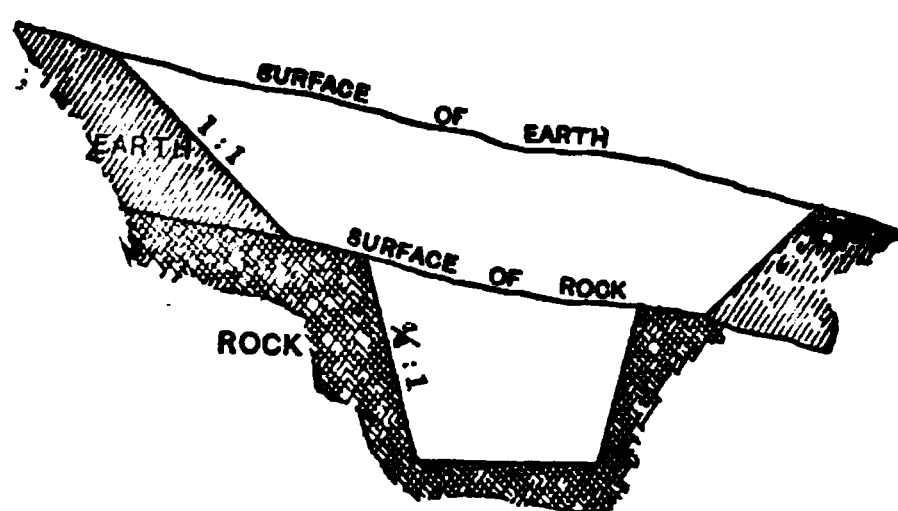


FIG. 41.

made. If borings have been made so that the contour of the rock surface is accurately known, then the true cross-section may be determined. The rock and earth should be calculated separately, and this will require an accurate knowledge of where the rock “runs out”—a difficult matter when it must be determined by boring. During construction the center part of the earth cut would be taken out first and the cut widened until a sufficient width of rock surface had been exposed so that the rock cut would have its proper width and side slopes. Then the earth slopes could be cut down at the proper angle. A “berm” of about three feet is usually left on the edges of the rock cut as a margin of safety against a possible sliding of the earth slopes. After the work is done, the amount of excavation that has been made is readily computable, but accurate preliminary estimates are difficult. The area of the cross-section of earth in the figure must be determined by a method similar to that developed for borrow-pits (see § 89).

62. Width of roadbed. Owing to the large and often disproportionate addition to volume of cut or fill caused by the addition of even one foot to the width of roadbed, there is a natural tendency to reduce the width until embankments become unsafe and cuts are too narrow for proper drainage. The cost of maintenance of roadbed is so largely dependent on the drainage of the roadbed that there is true economy in making an

ample allowance for it. The practice of some of the leading railroads of the country in this respect is given in the following table, in which are also given some data belonging more properly to the subject of superstructure.

WIDTH OF ROADBED FOR SINGLE AND DOUBLE TRACK—SLOPE RATIOS—DISTANCES BETWEEN TRACK CENTERS.

Road.	Single Track.		Double Track.		Slope Ratios.		Dist. between Track Centers.
	Cut.	Fill.	Cut.	Fill.	Cut.	Fill.	
A., T. & Santa Fé....	{ 28' earth 23' rock	20	.....	.....	1 : 1 1 1/4 : 1	1.5 : 1	
Chl., Burl. & Quincy	14 + (2 × 5) *	16	28 + (2 × 5)	30	1.5 : 1	1.5 : 1	14'
Chl., Mil. & St. Paul.	18 + (2 × 6)	20 to 24	31 + (2 × 6)	33 to 37	1.5 : 1	1.5 : 1	13'
C., C., C. & St. Louis	20 + (2 × 4)	20	33 + (2 × 4)	33	1.5 : 1	1.5 : 1	13'
Illinois Central.....	32.5	18	.....	.....	1.5 : 1	1.5 : 1	
Erie	20' 8 1/2"	20' 8 1/2"	33' 8 1/2"	33' 8 1/2"	1.5 : 1	1.5 : 1	13'
Lehigh Valley.....	14 + (2 × 3.5)	16	27 + (2 × 3.5)	30	1 : 1	1.5 : 1	13'
L. S. & Michigan So.	.....	.....	33 + (2 × 7.25)	32	1.5 : 1	1.5 : 1	13'
Louisville & Nashv..	13 + (2 × 4.5)	16	.....	.....	1 : 1	1.5 : 1	
Michigan Central....	.....	.....	33 + (2 × 2.5)	33	1.5 : 1	1.5 : 1	13'
N. Y. N. H. & H....	.....	.....	30	30	1.5 : 1	1.5 : 1	12'
Norfolk & Western...	{ 21' 2" earth 16' rock	17' 2"	34' 2" earth	30' 2"	1.5 : 1	1.5 : 1	13'
		.....	29' rock	.....	1 1/4 : 1 1 1/2 : 1	{	13'
Pennsylvania.....	{ 19' 2" light traffic 27' 2" heavy "	19' 2"					
Union Pacific... ..	14 + (2 × 3.5)	16	31' 4" + (2 × 4)	31' 4"	1.5 : 1	1.5 : 1	12' 2"
			.....	.....	1 : 1	1.5 : 1	

* (2 × 5) signifies two ditches each 5 feet wide: the following cases should be interpreted similarly.

It may be noted from the above table that the average width for an *earthwork* cut, single track, is about 24.7 feet, with a minimum of 19 feet 2 inches. The widths of fills, single track, average over 18 feet, with numerous minimums of 16 feet. The widths for double track may be found by adding the distance between track centers, which is usually 13 feet.

63. Form of subgrade. The stability of the roadbed depends largely on preventing the ballast and subsoil from becoming saturated with water. The ballast must be porous so that it will not retain water, and the subsoil must be so constructed that it will readily drain off the rain-water that soaks through the ballast. This is accomplished by giving the subsoil a curved form, convex

upward, or a surface made up of two or three planes, the two outer planes having a slope of about 1 : 24 (sometimes more and sometimes less, depending on the soil) and the middle plane, if three are used, being level. When a circular form is used, a crowning of 6 inches in a total width of 17 or 18 feet is generally used. Occasionally the subgrade is made level, especially in rock-cuts, but if the subsoil is previously compressed by rolling, as required on the N. Y. C. & H. R. R. R., or if the subsoil is drained by tile drains laid underneath the ditches, the necessity for slopes is not so great. Rock cuts are generally required to be excavated to one foot below subgrade and then filled up again to subgrade with the same material, if it is suitable.

64. Ditches. “The stability of the track depends upon the strength and permanence of the roadbed and structures upon which it rests; whatever will protect them from damage or prevent premature decay should be carefully observed. The worst enemy is WATER, and the further it can be kept away from the track, or the sooner it can be diverted from it, the better the track will be protected. Cold is damaging only by reason of the water which it freezes; therefore the first and most important provision for good track is drainage.” (Rules of the Road Department, Illinois Central R. R.)

The form of ditch generally prescribed has a flat bottom 12" to 24" wide and with sides having a minimum slope, except in rock-work, of 1 : 1, more generally 1.5 : 1 and sometimes 2 : 1. Sometimes the ditches are made V-shaped, which is objectionable unless the slopes are low. The best form is evidently that which will cause the greatest flow for a given slope, and this will evidently be the form in which the ratio of area to wetted perimeter is the largest. The semicircle fulfills this condition better than any other form, but the nearly vertical sides would be difficult to maintain. (See Fig. 42.) A ditch, with a flat bottom and such slopes as the soil requires, which approximates to the circular form will therefore be the best.



FIG. 42.

When the flow will probably be large and at times rapid it will be advisable to pave the ditches with stone, especially if the soil is easily washed away. Six-inch tile drains, placed 2' under the ditches, are prescribed on some roads. (See Fig. 43.) No better method could be devised to insure a dry subsoil. The ditches through cuts should be led off at the end of the cut so that the adjacent embankment will not be injured.

Wherever there is danger that the drainage from the land above a cut will drain down into the cut, a ditch should be made near the edge of the cut to intercept this drainage, and this ditch should be continued, and paved if necessary, to a point where the outflow will be harmless. Neglect of these simple and inexpensive precautions frequently causes the soil to be loosened on the shoulders of the slopes during the progress of a heavy rain, and results in a landslide which will cost more to repair than the ditches which would have prevented it for all time.

Ditches should be formed along the bases of embankments; they facilitate the drainage of water from the embankment, and may prevent a costly slip and disintegration of the embankment.

65. Effect of sodding the slopes, etc. Engineers are unanimously in favor of rounding off the shoulders and toes of embankments and slopes, sodding the slopes, paving the ditches, and providing tile drains for subsurface drainage, all to be put in during original construction. (See Fig. 43.) Some of the highest grade specifications call for the removal of the top layer of vegetable soil from cuts and from under proposed fills to some convenient place, from which it may be afterwards spread on the slopes, thus facilitating the formation of sod from grass-seed. But while engineers favor these measures and their economic value may be readily demonstrated, it is generally impossible to obtain the authorization of such specifications from railroad directors and promoters. The addition to the original cost of the roadbed is considerable, but is by no means as great as the capitalized value of the extra cost of maintenance resulting from the usual practice. Fig. 43 is a copy of

CUSTOMARY SECTION OF ROADBED ON EMBANKMENT.

FIG. 48.—“WHITTEMORE ON RAILWAY EXCAVATION AND EMBANKMENTS,”
Trans. Am. Soc. C. E., Sept. 1894

designs * presented at a convention of the American Society of Civil Engineers by Mr. D. J. Whittemore, Past President of the Society and Chief Engineer of the Chi., Mil. & St. Paul R.R. The "customary sections" represent what is, with some variations of detail, the practice of many railroads. The "proposed sections" elicited unanimous approval. They should be adopted when not prohibited by financial considerations.

EARTHWORK SURVEYS.

66. Relation of actual volume to the numerical result. It should be realized at the outset that the accuracy of the result of computations of the volume of any given mass of earthwork has but little relation to the accuracy of the mere numerical work. The process of obtaining the volume consists of two distinct parts. In the first place it is assumed that the volume of the earthwork may be represented by a more or less complicated geometrical form, and then, secondly, the volume of such a geometrical form is computed. A desire for simplicity (or a frank willingness to accept approximate results) will often cause the cross-section men to assume that the volume may be represented by a very simple geometrical form which is really only a very rough approximation to the true volume. In such a case, it is only a waste of time to compute the volume with minute numerical accuracy. One of the first lessons to be learned is that economy of time and effort requires that the accuracy of the numerical work should be kept proportional to the accuracy of the cross-sectioning work, and also that the accuracy of both should be proportional to the use to be made of the results. The subject is discussed further in § 94.

67. Prismoids. To compute the volume of earthwork, it is necessary to assume that it has some geometric form whose volume is readily determinable. The general method is to consider

* Trans. Am. Soc. Civil Eng., Sept. 1894.

the volume as consisting of a series of *prismoids*, which are solids having parallel plane ends and bounded by surfaces which may be formed by lines moving continuously along the edges of the bases. These surfaces may also be considered as the surfaces generated by lines moving along the edges joining the corresponding points of the bases, these edges being the directrices, and the lines being always parallel to either base, which is a plane director. The surfaces thus developed may or may not be planes. The volume of such a prismoid is readily determinable (as explained in § 70 *et seq.*), while its definition is so very general that it may be applied to very rough ground. The “two plane ends” are sections perpendicular to the axis of the road. The roadbed and side slopes (also plane) form three of the side surfaces. The only approximation lies in the degree of accuracy with which the plane (or warped) surfaces coincide with the actual surface of the ground between these two sections. This accuracy will depend (*a*) on the number of points which are taken in each cross-section and the accuracy with which the lines joining these points coincide with the actual cross-sections; (*b*) on the skill shown in selecting places for the cross-sections so that the warped surfaces shall coincide as nearly as possible with the surface of the ground. In fairly smooth country, cross-sections every 100 feet, placed at the even stations, are sufficiently accurate, and such a method simplifies the computations greatly; but in rough country cross-sections must be interpolated as the surface demands. As will be explained later, carelessness or lack of judgment in cross-sectioning will introduce errors of such magnitude that all refinements in the computations are utterly wasted.

68. Cross-sectioning. The process of cross-sectioning consists in determining at any place the intersection by a vertical plane of the prism of earth lying between the roadbed, the side slopes, and the natural surface. The intersection with the roadbed and side slopes gives three straight lines. The intersection with the natural surface is in general an irregular line. On smooth regular ground or when approximate results are accept-

able this line is assumed to be straight. According to the irregularity of the ground and the accuracy desired more and more "intermediate points" are taken.

The distance (d in Fig. 44) of the roadbed below (or above) the natural surface at the center is known or determined from

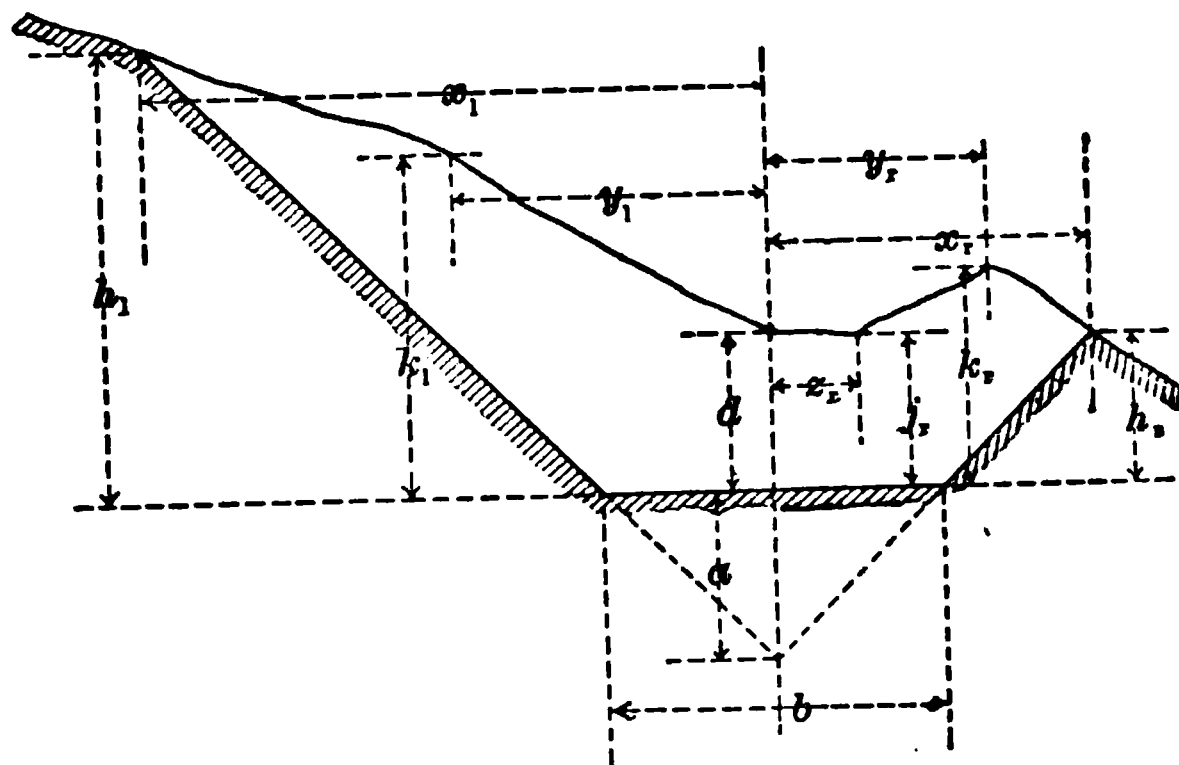


FIG. 44.

the profile or by the computed establishment of the grade line. The distances out from the center of all "breaks" are determined with a tape. To determine the elevations for a cut, set up a level at any convenient point so that the line of sight is higher than any point of the cross-section, and take a rod reading on the center point. This rod reading added to d gives the height of the instrument (H. I.) above the roadbed. Subtracting from H. I. the rod reading at any "break" gives the height of that point above the roadbed (h_1 , k_1 , h_2 , etc.). This is true for all cases in excavation. For fill, the rod reading at center minus d equals the H. I., which may be positive or negative. When negative, add to the "H. I." the rod readings of the intermediate points to get their depths below "grade"; when positive, subtract the "H. I." from the rod readings.

The heights or depths of these intermediate points above or below grade need only be taken to the nearest tenth of a foot, and the distances out from the center will frequently be suffi-

ciently exact when taken to the nearest foot. The roughness of the surface of farming land or woodland generally renders useless any attempt to compute the volume with any greater accuracy than these figures would imply unless the form of the ridges and hollows is especially well defined. The position of the slope-stake points is considered in the next section. Additional discussion regarding cross-sectioning is found in § 82.

69. Position of slope-stakes. The slope-stakes are set at the intersection of the required side slopes with the natural surface, which depends on the center cut or fill (d). The distance of

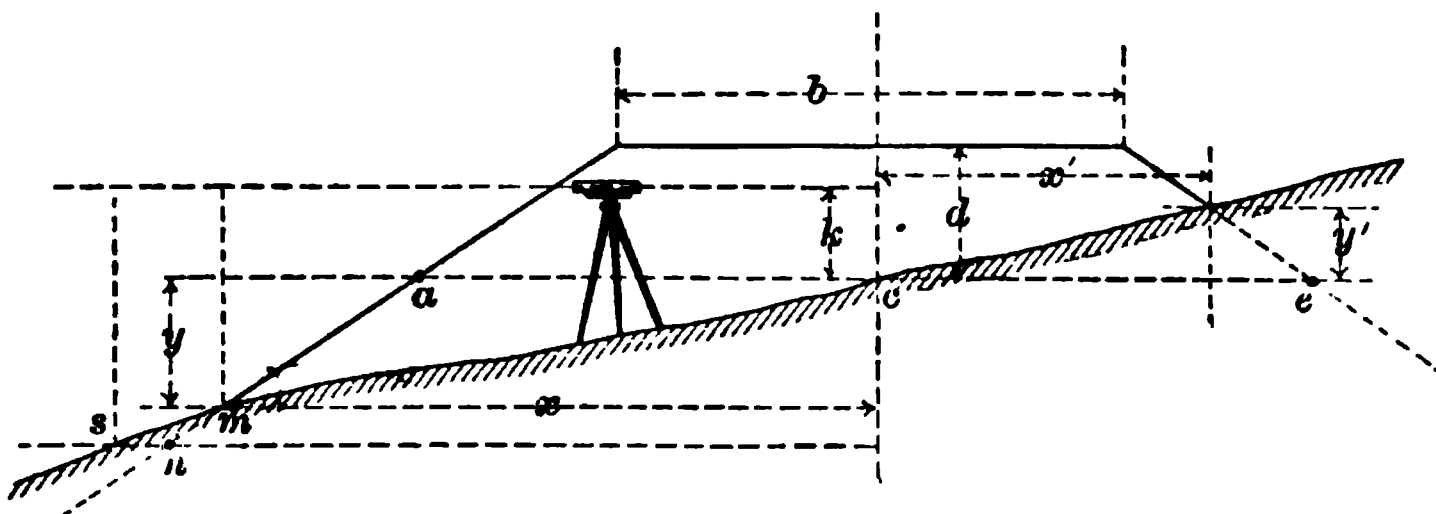


FIG. 45.

the slope-stake from the center for the lower side is $x = \frac{1}{2}b + s(d + y)$; for the up-hill side it is $x' = \frac{1}{2}b + s(d - y')$. s is the "slope ratio" for the side slopes, the ratio of horizontal to vertical. In the above equation both x and y are unknown. Therefore some position must be found by trial which will satisfy the equation. As a preliminary, the value of x for the point $a = \frac{1}{2}b + sd$, which is the value of x for *level* cross-sections. In the case of fills on sloping ground the value of x on the *down-hill* side is *greater* than this; on the *up-hill* side it is *less*. The difference in distance is s times the difference of elevation. Take a numerical case corresponding with Fig. 45. The rod reading on c is 2.9; $d = 4.2$; therefore the telescope is $4.2 - 2.9 = 1.3$ *below* grade. $s = 1.5 : 1$, $b = 16$. Hence for the point a (or for level ground) $x = \frac{1}{2} \times 16 + 1.5 \times 4.2 = 14.3$. At a distance out of 14.3 the ground is seen to be about 3 feet lower, which will not only require $1.5 \times 2 = 4.5$ more, but

enough additional distance so that the added distance shall be 1.5 times the additional drop. As a first trial the rod may be held at 24 feet out and a reading of, say, 8.3 is obtained. $8.3 + 1.3 = 9.6$, the depth of the point below grade. The point on the slope line (n) which has this depth below grade is at a distance from the center $x = 8 + 1.5 \times 9.6 = 22.4$. The point on the surface (s) having that depth is 24 feet out. Therefore the true point (m) is nearer the center. A second trial at 20.5 feet out gives a rod reading of, say, 7.1 or a depth of 8.4 below grade. This corresponds to a distance out of 20.6. Since the natural soil (especially in farming lands or woods) is generally so rough that a difference of elevation of a tenth or so may be readily found by slightly varying the location of the rod (even though the distance from the center is the same), it is useless to attempt too much refinement, and so in a case like the above the combination of 8.4 below grade and 20.6 out from center may be taken to indicate the proper position of the slope-stake. This is usually indicated in the form of a fraction, the distance out being the denominator and the height above (or below) grade being the numerator; the fact of *cut* or *fill* may be indicated by C or F . Ordinarily a second trial will be sufficient to determine with sufficient accuracy the true position of the slope-stake. Experienced men will frequently estimate the required distance out to within a few tenths at the first trial. The left-hand pages of the note-book should have the station number, surface elevation, grade elevation, center cut or fill, and rate of grade. The right-hand pages should be divided in the center and show the distances out and heights above grade of all points, as is illustrated in § 84. The notes should read up the page, so that when looking ahead along the line the figures are in their proper relative position. The "fractions" farthest from the center line represent the slope-stake points.

COMPUTATION OF VOLUME.

70. Prismoidal formula. Let Fig. 46 represent a triangular prismoid. The two triangles forming the ends lie in *parallel*

planes, but since the angles of one triangle are not equal to the corresponding angles of the other triangle, at least two of the surfaces must be *warped*. If a section, parallel to the bases, is

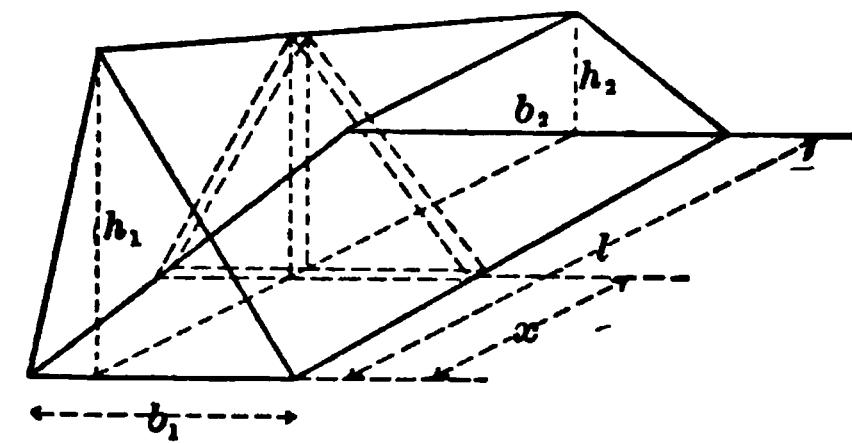


FIG. 46.

made at any point at a distance x from one end, the area of the section will evidently be

$$A_x = \frac{1}{2}b_x h_x = \frac{1}{2} \left[b_1 + (b_2 - b_1) \frac{x}{l} \right] \left[h_1 + (h_2 - h_1) \frac{x}{l} \right].$$

The volume of a section of infinitesimal length will be $A_x dx$, and the total volume of the prismoid will be *

$$\begin{aligned} \int_0^l A_x dx &= \frac{1}{2} \int_0^l \left[b_1 + (b_2 - b_1) \frac{x}{l} \right] \left[h_1 + (h_2 - h_1) \frac{x}{l} \right] dx \\ &= \frac{1}{2} \left[b_1 h_1 x + (b_2 - b_1) h_1 \frac{x^2}{2l} + b_1 (h_2 - h_1) \frac{x^2}{2l} \right. \\ &\quad \left. + (b_2 - b_1)(h_2 - h_1) \frac{x^3}{3l^2} \right]_0^l \\ &= \frac{1}{2} \left\{ b_1 h_1 l + [(b_2 - b_1) h_1 + b_1 (h_2 - h_1)] \frac{l}{2} + (b_2 - b_1)(h_2 - h_1) \frac{l}{3} \right\}, \end{aligned}$$

* Students unfamiliar with the Integral Calculus may take for granted the fundamental formulæ that $\int dx = x$, that $\int x dx = \frac{1}{2}x^2$, and that $\int x^2 dx = \frac{1}{3}x^3$; also that in integrating between the limits of l and 0 (zero), the value of the integral may be found by simply substituting l for x after integration.

$$\begin{aligned}
\int_0^l A_x dx &= \frac{l}{2} \left[\frac{1}{2} b_1 h_1 + \frac{1}{2} b_1 h_2 + \frac{1}{2} b_2 h_1 + \frac{1}{2} b_2 h_2 \right] \\
&= \frac{l}{6} \left[\frac{1}{2} b_1 h_1 + \frac{1}{2} b_1 (h_1 + h_2) + \frac{1}{2} b_2 (h_1 + h_2) + \frac{1}{2} b_2 h_2 \right] \\
&= \frac{l}{6} \left[\frac{1}{2} b_1 h_1 + 4 \left(\frac{1}{2} \cdot \frac{b_1 + b_2}{2} \cdot \frac{h_1 + h_2}{2} \right) + \frac{1}{2} b_2 h_2 \right] \\
&= \frac{l}{6} [A_1 + 4A_m + A_2], \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45)
\end{aligned}$$

in which A_1 , A_2 , and A_m are the areas respectively of the two bases and of the middle section. Note that A_m is *not* the mean of A_1 and A_2 , although it does not necessarily differ very greatly from it.

The above proof is absolutely independent of the values, absolute or relative, of b_1 , b_2 , h_1 or h_2 . For example, h_1 may be zero and the second base reduces to a line and the prismoid becomes wedge-shaped; or b_2 and h_2 may both vanish, the second base becoming a point and the prismoid reduces to a pyramid. Since every prismoid (as defined in § 67) may be reduced to a combination of triangular prismoids, wedges, and pyramids, and since the formula is true for any one of them individually, it is true for all collectively; therefore it may be stated that *

The volume of a prismoid equals one sixth of the perpendicular distance between the bases multiplied by the sum of the areas of the two bases plus four times the area of the middle section.

While it is always possible to compute the volume of any prismoid by the above method, it becomes an extremely complicated and tedious operation to compute the true value of the middle section if the end sections are complicated in form. It

* The student should note that the derivation of equation (45) does not complete the proof, but that the statements in the following paragraph are logically necessary for a general proof.

therefore becomes a simpler operation to compute volumes by approximate formulæ and apply, if necessary, a correction. The most common methods are as follows:

71. Averaging end areas. The volume of the triangular prismoid (Fig. 46), computed by averaging end areas, is $\frac{l}{2}[\frac{1}{2}b_1h_1 + \frac{1}{2}b_2h_2]$. Subtracting this from the true volume (as given in the equation above, Eq. (45)), we obtain the correction

$$\frac{l}{12}[(b_1 - b_2)(h_2 - h_1)]. \quad . \quad . \quad . \quad . \quad (46)$$

This shows that if either the h 's or b 's are equal, the correction vanishes; it also shows that if the bases are roughly similar and b varies roughly with h (which *usually* occurs, as will be seen later), the correction will be *negative*, which means that the method of averaging end areas *usually* gives *too large* results.

72. Middle areas. Sometimes the middle area is computed and the volume is assumed to be equal to the length times the middle area. This will equal $\frac{l}{2} \times \frac{b_1 + b_2}{2} \times \frac{h_1 + h_2}{2}$. Subtracting this from the true volume, we obtain the correction

$$\frac{l}{24}(b_1 - b_2)(h_1 - h_2). \quad . \quad . \quad . \quad . \quad (47)$$

As before, the form of the correction shows that if either the h 's or b 's are equal, the correction vanishes; also under the *usual* conditions, as before, the correction is *positive* and only one-half as large as by averaging end areas. Ordinarily the labor involved in the above method is no less than that of applying the exact prismoidal formula.

73. Two-level ground. When *approximate* computations of earthwork are sufficiently exact the field-work may be materially reduced by observing simply the center cut (or fill) and the

natural slope α , measured with a clinometer. The area of such a section (see Fig. 48) equals

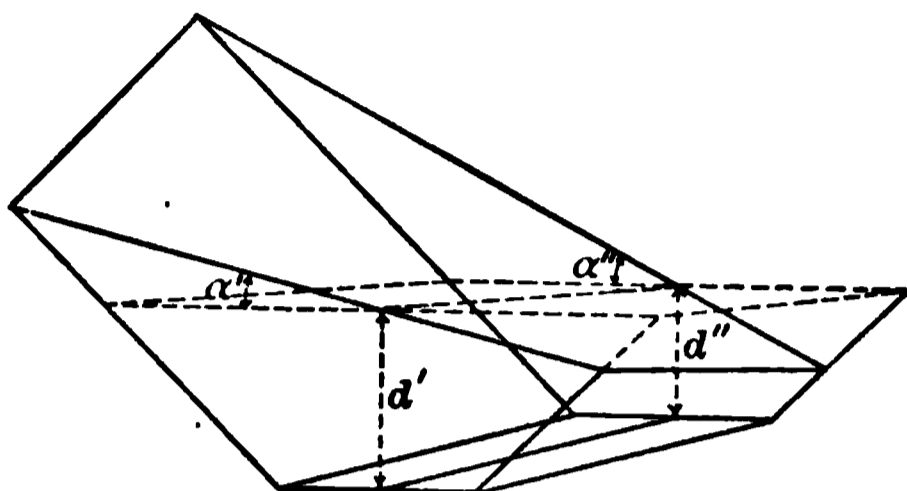


FIG. 47.

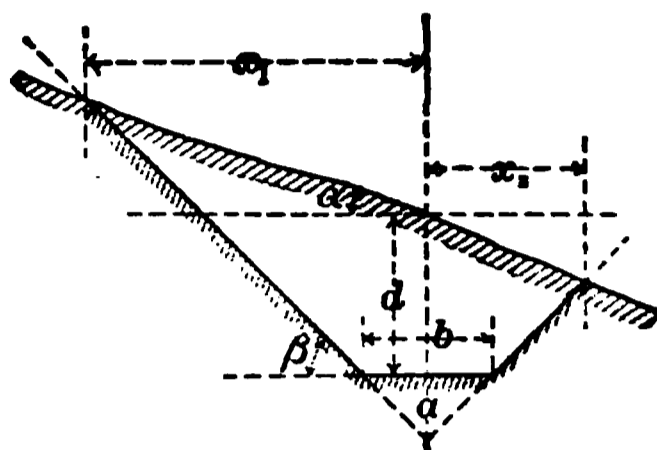


FIG. 48.

$$\frac{1}{2}(a + d)(x_i + x_r) - \frac{ab}{2}.$$

But

$$x_i \tan \beta = a + d + x_i \tan \alpha,$$

from which

$$x_i = \frac{a + d}{\tan \beta - \tan \alpha}.$$

Similarly,

$$x_r = \frac{a + d}{\tan \beta + \tan \alpha}.$$

Substituting,

$$\text{Area} = (a + d)^2 \frac{\tan \beta}{\tan^2 \beta - \tan^2 \alpha} - \frac{ab}{2}. \quad (48)$$

The values α , $\tan \beta$, $\tan^2 \beta$ are constant for all sections, so that it requires but little work to find the area of any section. As this method of cross-sectioning implies considerable approximation, it is generally a useless refinement to attempt to compute the volume with any greater accuracy than that obtained by averaging end areas. It may be noted that it may be easily proved that the correction to be applied is of the same form as that found in § 71 and equals

$$\frac{l}{12}[(x_i' + x_r') - (x_i'' + x_r'')][(d'' + a) - (d' + a)],$$

which reduces to

$$\text{Correction} = \frac{l}{6} \left\{ \left[(a+d') \frac{\tan \beta}{\tan^2 \beta - \tan^2 \alpha'} - (a+d'') \frac{\tan \beta}{\tan^2 \beta - \tan^2 \alpha''} \right] [d'' - d'] \right\}. \quad (49)$$

When $d'' = d'$ the correction vanishes. This shows that when the center heights are equal there is no correction—regardless of the slope. If the slope is uniform throughout, the form of the correction is simplified and is invariably *negative*. Under the usual conditions the correction is *negative*, i.e., the method *generally* gives *too large* results.

74. Level sections. When the country is very level or when only approximate preliminary results are required, it is sometimes assumed that the cross-sections are level. The method of level sections is capable of easy and rapid computation. The area may be written as

$$(a + d)^2 s - \frac{ab}{2}. \quad . \quad . \quad . \quad . \quad . \quad (50)$$

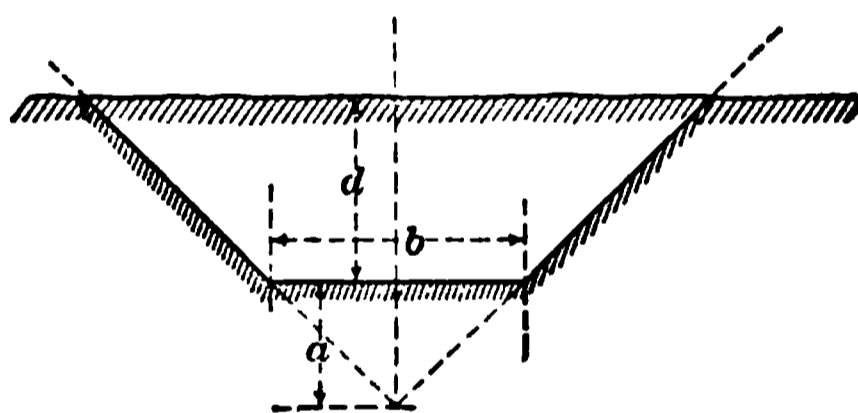


FIG. 49.

This also follows from Eq. (48) when $\alpha = 0$ and $\tan \beta = \frac{1}{s}$. s here represents the “slope ratio,” i.e., the ratio of the horizontal projection of the slope to the vertical. A table is very readily formed giving the area in square feet of a section of given depth and for any given width of roadbed and ratio of side-slopes. The area may also be readily determined (as illustrated in the following example) without the use of such a table; a table of squares will facilitate the work. Assuming

the cross-sections at equal distances ($= l$) apart, the total approximate volume for any distance will be

$$\frac{l}{2}[A_0 + 2(A_1 + A_2 + \dots + A_{n-1}) + A_n]. \quad (51)$$

The prismoidal correction may be directly derived from Eq. (46) as $\frac{l}{12}[2(a + d')s - 2(a + d'')s][(a + d'') - (a + d')]$, which reduces to

$$-\frac{ls}{6}(d' - d'')^2 \quad \text{or} \quad -\frac{l}{12}\frac{b}{a}(d' - d'')^2. \quad (52)$$

This may also be derived from Eq. (49), since $\alpha = 0$, $\tan \alpha = 0$, and $\tan \beta = 2a \div b$. This correction is *always* negative, showing that the method of averaging end areas, when the sections are level, always gives too large results. The prismoidal correction for any one prismoid is therefore a constant times the *square* of a difference. The squares are always positive whether the differences are positive or negative. The correction therefore becomes

$$-\frac{l}{12}\frac{b}{a}\Sigma(d' \sim d'')^2. \quad (53)$$

75. Numerical example: level sections. Given the following center heights for the same number of consecutive stations 100 feet apart; width of roadbed 18 feet; slope $1\frac{1}{2}$ to 1.

The products in the fifth column may be obtained very readily and with sufficient accuracy by the use of the slide-rule described in § 79. The products should be considered as $(a + d)(a + d) \div \frac{1}{s}$. In this problem $s = 1\frac{1}{2}, \frac{1}{s} = .6667$.

To apply the rule to the first case above, place 6667 on scale B over 89 on scale A , then opposite 89 on scale B will be found

118.8 on scale *A*. The position of the decimal point will be evident from an approximate mental solution of the problem.

Sta.	Center Height.	$a + d$	$(a + d)^2$	$(a + d)^2 s$	Areas.	$d' \sim d''$	$(d' \sim d'')^2$
17	2.9	8.9	79.21	118.81	118.81		
18	4.7	10.7	114.49	171.74	$\times 2 = \begin{cases} 343.48 \\ 491.52 \\ 939.86 \\ 312.12 \\ 86.64 \end{cases}$	1.8	3.24
19	6.8	12.8	163.84	245.76		2.1	4.41
20	11.7	17.7	313.29	469.93		4.9	24.01
21	4.2	10.2	104.04	156.06		7.5	56.25
22	1.6	7.6	57.76	86.64		2.6	6.76

$$\frac{ab}{2} = \frac{6 \times 18}{2} = 54$$
$$10 \times 54 = \frac{540}{1752.43}$$
$$\frac{1752.43 \times 100}{2 \times 27} = 3245 \text{ cub. yards} = \text{approx. vol.}$$
$$\text{Corr.} = - \frac{100 \times 18}{12 \times 6 \times 27} \times 94.67 = - 91 \text{ cub. yds.}$$
$$3245 - 91 = 3154 \text{ cub. yds.} = \text{exact volume.}$$

$$\frac{2292.43}{1752.43} = 94.67$$

The above demonstration of the correction to be applied to the approximate volume, found by averaging end areas, is introduced mainly to give an idea of the amount of that correction. Absolutely level sections are practically unknown, and the error involved in assuming any given sections as truly level will ordinarily be greater than the computed correction. If greater accuracy is required, more points should be obtained in the cross-sectioning, which will generally show that the sections are not truly level.

76. Equivalent sections. When sections are very irregular the following method may be used, especially if great accuracy is not required. The sections are plotted to scale and then a uniform slope line is obtained by stretching a thread so that the undulations are averaged and an *equivalent section* is obtained. The *center depth* (*d*) and the *slope angle* (α) of this line can be obtained from the drawing, but it is more convenient to measure the distances (x_1 and x_r) from the center. The area

77. Equivalent level sections. These sloping “two-level” sections are sometimes transformed into “level sections of equal area,” and the volume computed by the method of level sections (§ 74). But the true volume of a prismoid with sloping ends does not agree with that of a prismoid with equivalent bases and level ends except under special conditions, and when this method is used a correction must be applied if accuracy is desired, although, as intimated before, the assumption that the sections have uniform slopes will frequently introduce greater inaccuracies than that of this method of computation. The following demonstration is therefore given to show the scope and limitations of the errors involved in this much used method.

In Fig. 50, let d_1 be the center height which gives an

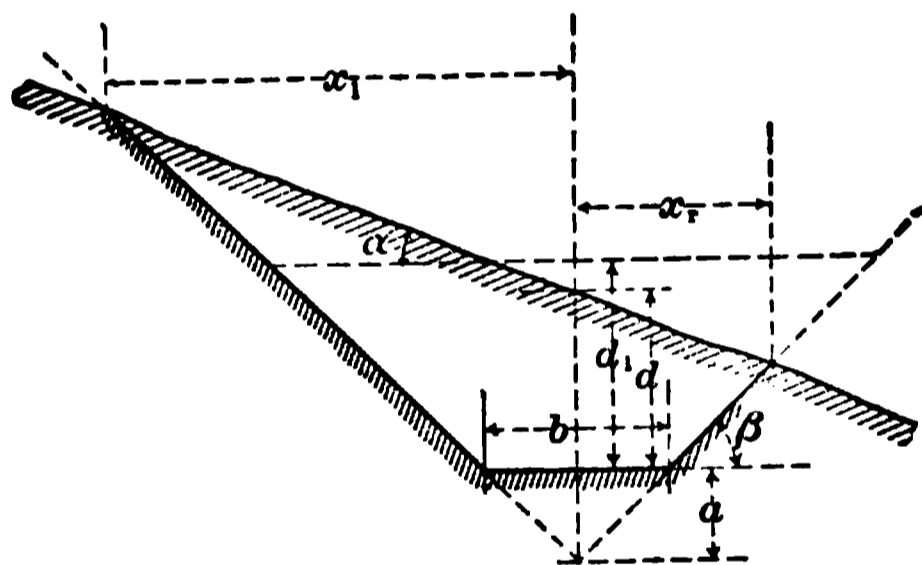


FIG. 50.

equivalent level section. The area will equal $(a + d_1)s - \frac{ab}{2}$, which must equal the area given in § 76, $\frac{x_r x_l}{s} - \frac{ab}{2}$. $s = \frac{b}{2a}$.

$$\therefore (a + d_1)s = \frac{x_r x_l}{s},$$

$$\text{or } a + d_1 = \frac{\sqrt{x_l x_r}}{s}. \quad . \quad . \quad . \quad . \quad (56)$$

To obtain d_1 directly from notes, given in terms of d and α ,

we may substitute the values of x_i and x_r given in § 73, which gives

$$a + d_i = (a + d) \frac{\tan \beta}{\sqrt{\tan^2 \beta - \tan^2 \alpha}} = \frac{a + d}{\sqrt{1 - s^2 \tan^2 \alpha}}. \quad (57)$$

The *true* volume of the equivalent section may be represented by

$$\frac{ls}{6} \left[(a + d_i')^2 + 4 \left(\frac{a + d_i'}{2} + \frac{a + d_i''}{2} \right)^2 + (a + d_i'')^2 \right].$$

From this there should be subtracted the volume of the “grade prism” under the roadbed to obtain the volume of the cut that would be actually excavated, but in the following comparison, as well as in other similar comparisons elsewhere made, the volume of the grade prism invariably cancels out, and so for the sake of simplicity it will be disregarded. This expression for volume may be transposed to

$$\frac{ls}{6} \left[\frac{x_i' x_r'}{s^2} + 4 \left(\frac{\sqrt{x_i' x_r'}}{2s} + \frac{\sqrt{x_i'' x_r''}}{2s} \right)^2 + \frac{x_i'' x_r''}{s^2} \right].$$

The true volume of the prismoid with sloping ends is (see § 76)

$$\frac{l}{6} \left[\frac{x_i' x_r'}{s} + 4 \left(\left(\frac{x_i' + x_i''}{2} \right) \left(\frac{x_r' + x_r''}{2} \right) \frac{1}{s} \right) + \frac{x_i'' x_r''}{s} \right].$$

The difference of the two volumes

$$\begin{aligned} &= \frac{l}{6s} (x_i' x_r' + x_i'' x_r' + x_i' x_r'' + x_i'' x_r'' - x_i' x_r' - 2\sqrt{x_i' x_r' x_i'' x_r''} - x_i'' x_r'') \\ &= \frac{l}{6s} (\sqrt{x_i' x_r''} - \sqrt{x_i'' x_r'})^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (58) \end{aligned}$$

This shows that “equivalent level sections” do *not* in general give the true volume, there being an exception when

$x_i'x_r'' = x_i''x_r'$. This condition is fulfilled when the slope is uniform, i.e., when $\alpha' = \alpha''$. When this is nearly so the error is evidently not large. On the other hand, if the slopes are inclined in opposite directions the error may be very considerable, particularly if the angles of slope are also large.

78. Three-level sections. The next method of cross-sectioning in the order of complexity, and therefore in the order of

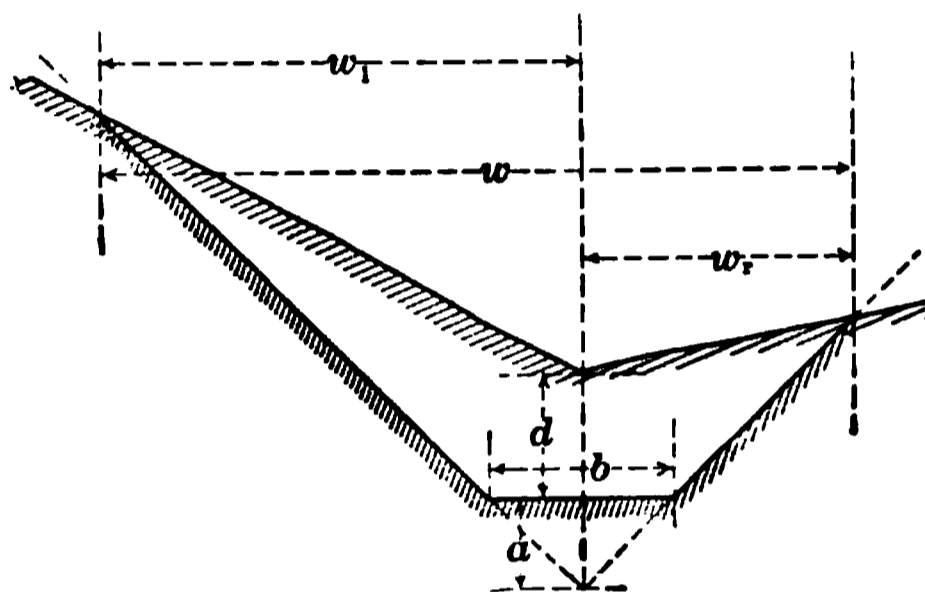


FIG. 51.

accuracy, is the method of three-level sections. The area of the section is $\frac{1}{2}(a + d)(w_r + w_i) - \frac{ab}{2}$, which may be written $\frac{1}{2}(a + d)w - \frac{ab}{2}$, in which $w = w_r + w_i$. If the volume is computed by averaging end areas, it will equal

$$\frac{l}{4} [(a + d')w' - ab + (a + d'')w'' - ab]. \quad (59)$$

If we divide by 27 to reduce to cubic yards, we have, when $l = 100$,

$$\text{Vol}_{(\dots)} = \frac{25}{27}(a + d')w' - \frac{25}{27}ab + \frac{25}{27}(a + d'')w'' - \frac{25}{27}ab.$$

For the next section

$$\text{Vol}_{(\dots)} = \frac{25}{27}(a + d'')w'' - \frac{25}{27}ab + \frac{25}{27}(a + d''')w''' - \frac{25}{27}ab.$$

For a partial station length compute as usual and multiply result by $\frac{\text{length in feet}}{100}$. The prismoidal correction may be obtained by applying Eq. (46) to each side in turn. For the left side we have

$$\frac{l}{12}[(a + d') - (a + d'')](w_i'' - w_i'), \quad \text{which equals}$$

$$\frac{l}{12}(d' - d'')(w_i'' - w_i').$$

For the right side we have, similarly,

$$\frac{l}{12}(d' - d'')(w_r'' - w_r').$$

The total correction therefore equals

$$\begin{aligned} & \frac{l}{12}(d' - d'')[(w_i'' + w_r'') - (w_i' + w_r')] \\ &= \frac{l}{12}(d' - d'')(w'' - w'). \end{aligned}$$

Reduced to cubic yards, and with $l = 100$,

$$\text{Pris. Corr.} = \frac{25}{81}(d' - d'')(w'' - w'). \quad . \quad . \quad (60)$$

When this result is compared with that given in Eq. (55) there is an apparent inconsistency. If two-level ground is considered as but a special case of three-level ground, it would seem as if the same laws should apply. If, in Eq. (55), $x_r' = x_r''$, and x_i'' is different from x_i' , the equation reduces to zero; but in this case d' would also be different from d'' ; and since $x_i' + x_r'$ would $= w'$, and $x_i'' + x_r'' = w''$ in Eq. (60), $w'' - w'$ would not equal zero and the correction would be some finite quantity and not zero. The explanation lies in the difference in the form and volume of the prismoids, according to the method of the

formation of the warped surfaces. If the surface is supposed to be generated by the locus of a line moving parallel to the ends as plane directors and along two *straight* lines lying *in* the side-slopes, then x_l^{mid} will equal $\frac{1}{2}(x_l' + x_l'')$, and x_r^{mid} will equal $\frac{1}{2}(x_r' + x_r'')$, but the profile of the center line will *not* be straight and d^{mid} will *not* equal $\frac{1}{2}(d' + d'')$. On the other hand, if the surfaces be generated by *two* lines moving parallel to the ends as plane directors and along a *straight* center line and straight side lines lying in the slopes, a warped surface will be generated each side of the center line, which will have uniform slopes on each side of the center at the two ends and *nowhere else*. This shows that when the upper surface of earth-work is warped (as it generally is), two-level ground should not be considered as a special case of three-level ground. This discussion, however, is only valuable to explain an apparent inconsistency and error. The method of two-level ground should only be used when such refinements as are here discussed are of no importance as affecting the accuracy.

The following example is given to illustrate the method of three-level sections.

Station.	Center.	Left.	Right.	$a + d$	w	Yards.		$d' - d''$	$w'' - w'$	Pris. Corr.	$x_l \sim x_r$	$\frac{V(x_l \sim x_r)}{3R}$	Curv. Corr.*
17	2.6F	$\frac{10.6F}{22.9}$ 8.2	$\frac{0.8F}{8.2}$	7.8	31.1	210					14.7	+1	
18	8.1F	$\frac{15.8F}{30.7}$ 12.1	$\frac{3.4F}{12.1}$	12.8	42.8	507	595	-5.5	+11.7	-20	18.6	+3	+4
+40	10.7F	$\frac{20.2F}{37.3}$ 14.2	$\frac{4.8F}{14.2}$	15.4	51.5	734	448	-2.6	+ 8.7	- 3	23.1	+6	+4
19	6.4F	$\frac{14.0F}{28.0}$ 10.1	$\frac{2.1F}{10.1}$	11.1	38.1	392	602	+4.3	-13.4	-11	17.9	+2	+5
20	3.7F	$\frac{5.8F}{15.7}$ 7.3	$\frac{0.2F}{7.3}$	8.4	23.0	179	449	+2.7	-15.1	-13	8.4	+1	+3

Roadbed, 14' wide in fill.
Slope $1\frac{1}{2}$ to 1.
 $a = \frac{b}{2s} = \frac{14}{3} = 4.7;$
 $\frac{25}{27}ab = 61.$

Approx. Vol. = 2094
Pris. corr. = 47
True Vol. = 2047 (disregarding curv. corr).*

* For the Derivation of the curvation correction, see § 93.

-47

+16

In the first column of yards

$$210 = \frac{25}{81}(a + d)w = \frac{25}{81} \times 7.3 \times 31.1;$$

507, 734, etc., are found similarly;

$$595 = 210 - 61 + 507 - 61;$$

$$448 = \frac{40}{100}(507 - 61 + 734 - 61);$$

$$602 = \frac{60}{100}(734 - 61 + 392 - 61);$$

$$449 = 392 - 61 + 179 - 61.$$

For the prismoidal correction,

$$\begin{aligned} -20 &= \frac{25}{81}(d' - d'')(w'' - w') = \frac{25}{81}(2.6 - 8.1)(42.8 - 31.1) \\ &= \frac{25}{81}(-5.5)(+11.7). \end{aligned}$$

For the next line, $-3 = \frac{40}{100}[\frac{25}{81}(-2.8)(+8.7)]$, and similarly for the rest. The “*F*” in the columns of center heights, as well as in the columns of “right” and “left,” are inserted to indicate *fill* for all those points. Cut would be indicated by “*C*.”

79. Computation of products. The quantities $\frac{25}{27}(a + d)w$ and $\frac{25}{27}ab$ represent in each case the product of two variable terms and a constant. These products are sometimes obtained from tables which are calculated for all ordinary ranges of the variable terms as arguments. A similar table computed for $\frac{25}{81}(d' - d'')(w'' - w')$ will assist similarly in computing the prismoidal correction. Prof. Charles L. Crandall, of Cornell University, is believed to be the first to prepare such a set of tables, which were first published in 1886 in “Tables for the Computation of Railway and Other Earthwork.” Another

easy method of obtaining these products is by the use of a slide-rule. A slide-rule has been designed by the author to accompany this volume. It is designed particularly for this special work, although it may be utilized for many other purposes for which slide-rules are valuable. To illustrate its use, suppose $(a + d) = 28.2$, and $w = 62.4$; then

$$\frac{25}{27}(a + d)w = \frac{28.2 \times 62.4}{1.08}.$$

Set 108 (which, being a constant of frequent use, is specially marked) on the sliding scale (*B*) opposite 282 on the other scale (*A*), and then opposite 624 on scale *B* will be found 1629 on scale *A*, the 162 being read directly and the 9 read by estimation. Although strict rules may be followed for pointing off the final result, it only requires a very simple mental calculation to know that the result must be 1629 rather than 162.9 or 16290. For products less than 1000 cubic yards the result may be read directly from the scale; for products between 1000 and 5000 the result may be read directly to the nearest 10 yards, and the tenths of a division estimated. Between 5000 and 10,000 yards the result may be read directly to the nearest 20 yards, and the fraction estimated; but prisms of such volume will never be found as simple triangular prisms—at least, an assumption that any mass of ground was as regular as this would probably involve more error than would occur from faulty estimation of fractional parts. Facilities for reading as high as 10,000 cubic yards would not have been put on the scale except for the necessity of finding such products as $\frac{25}{27}(9.1 \times 9.5)$, for example. This product would be read off from the same part of the rule as $\frac{25}{27}(91 \times 95)$. In the first case the product (80.0) could be read directly to the nearest .2 of a cubic yard, which is unnecessarily accurate. In the other case, the product (8004) could only be obtained by estimating $\frac{4}{10}$ of a division.

The computation for the prismoidal correction may be made

similarly except that the divisor is 3.24 instead of 1.08. For example, $\frac{5}{8}(5.5 \times 11.7) = \frac{5.5 \times 11.7}{3.24}$. Set the 324 on scale *B* (also specially marked like 108) opposite 55 on scale *A*, and proceed as before.

80. Five-level sections. Sometimes the elevations over each edge of the roadbed are observed when cross-sectioning. These are distinctively termed “five-level sections.” If the center, the slope-stakes, and *one* intermediate point on each side (*not* necessarily over the edge of the roadbed) are observed, it is termed an “irregular section.” The field-work of cross-sectioning five-level sections is no less than for irregular sections with one intermediate point; the computations, although capable of peculiar treatment on account of the location of the intermediate point, are no easier, and in some respects more laborious; the cross-sections obtained will not in general represent the actual cross-sections as truly as when there is perfect freedom in locating the intermediate point; as it is generally inadvisable or unnecessary to employ five-level sections throughout the length of a road, the change from one method to another adds a possible element of inaccuracy and loses the advantage of uniformity of method, particularly in the notes and *form* of computations. On these accounts the method will not be further developed, except to note that this case, as well as any other, may be solved by dividing the whole prismoid into triangular prismoids, computing the volume by averaging end areas, and computing the prismoidal correction by adding the computed corrections for each elementary triangular prismoid.

81. Irregular sections. In cross-sectioning irregular sections, the distance from the center and the elevation above “grade” of every “break” in the cross-section must be observed. The area of the irregular section may be obtained by computing the area of the trapezoids (*five*, in Fig. 44) and subtracting the two external triangles. For Fig. 44 the area would be

$$\begin{aligned} & \frac{h_l + k_l}{2}(x_l - y_l) + \frac{k_l + d}{2}y_l + \frac{d + j_r}{2}z_r + \frac{j_r + k_r}{2}(y_r - z_r) \\ & + \frac{k_r + h_r}{2}(x_r - y_r) - \frac{h_l}{2}\left(x_l - \frac{b}{2}\right) - \frac{h_r}{2}\left(x_r - \frac{b}{2}\right). \end{aligned}$$

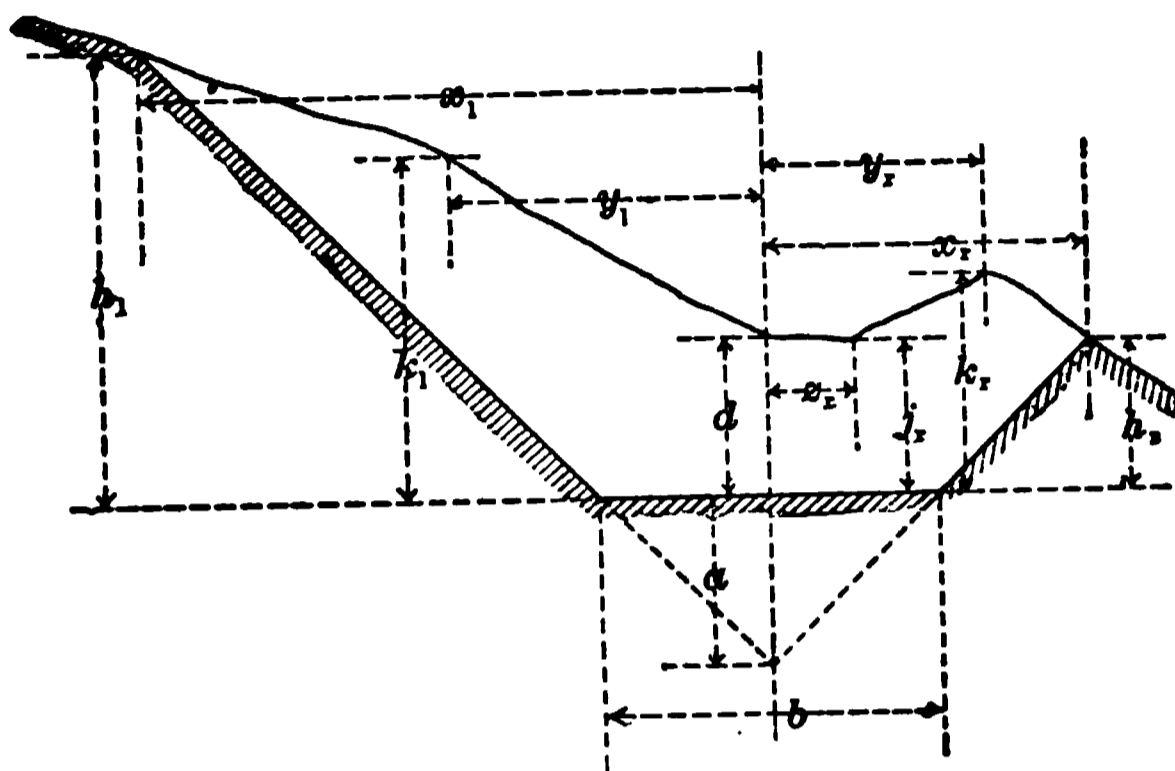


FIG. 44.

Expanding this and collecting terms, of which many will cancel, we obtain

$$\begin{aligned} \text{AREA} = \frac{1}{2} \bigg[& x_l k_l + y_l(d - h_l) + x_r k_r + y_r(j_r - h_r) \\ & + z_r(d - k_r) + \frac{b}{2}(h_l + h_r) \bigg]. \quad (61) \end{aligned}$$

An examination of this formula will show a perfect regularity in its formation which will enable one to write out a similar formula for any section, no matter how irregular or how many points there are, without any of the preliminary work. The formula may be expressed in words as follows:

AREA equals one-half the sum of products obtained as follows:
the distance to each slope-stake times the height above grade of the point next inside the slope-stake;

the distance to each intermediate point in turn times the height of the point just inside minus the height of the point just outside;

finally, one-half the width of the roadbed times the sum of the slope-stake heights.

If one of the sides is perfectly regular from center to slope-stake, it is easy to show that the rule holds literally good. The “point next inside the slope-stake” in this case is the center; the intermediate terms for that side vanish. The *last term* must always be used. The rule holds good for three-level sections, in which case there are three terms, which may be reduced to two. Since these two terms are both variable quantities for each cross-section, the special method, given in § 78, in which one term $\left(\frac{ab}{2}\right)$ is a constant for all sections, is preferable. In the general method, each intermediate “break” adds another term.

82. Volume of an irregular prismoid. If there is a break at one cross-section which is not represented at the next, the ridge (or hollow) implied by that break is supposed to “vanish” at the next section. In fact, the volume will not be correctly

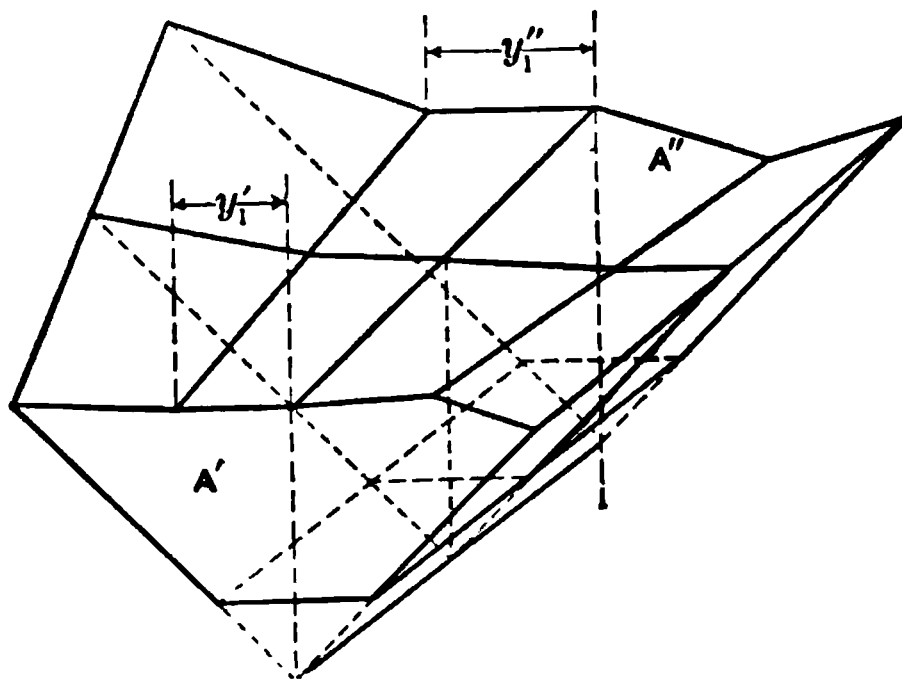


FIG. 52.

represented unless a cross-section is taken at the point where the ridge or hollow “vanishes” or “runs out.” To obtain the true prismoidal correction it is necessary to observe on the ground the place where a break in an adjacent section, which is not represented in the section being taken, runs out. For example, in Fig. 52, the break on the left of section A'' , at a

distance of y_i'' from the center, is observed to run out in section A' at a distance of y_i' from the center. The volume of the prismoid, computed by the prismoidal formula as in § 70, will involve the midsection, to obtain the dimension of which will require a laborious computation. A simpler process is to compute the volume by averaging end areas as in § 81 and apply a prismoidal correction. To do this write out an expression for each end area similar to that given in Eq. 61. The sum of these areas times $\frac{l}{2}$ gives the approximate volume. As before,

for partial station lengths, multiply the result by $\frac{\text{length in feet}}{100}$.

There will be no constant subtractive term, $\frac{2}{3}ab$, as in § 78. The *true* prismoidal correction may be computed, as in § 83, or the following approximate method may be used: Consider the irregular section to be three-level ground *for the purpose of computing the correction* only. This has the advantage of less labor in computation than the use of the true prismoidal correction, and although the error involved may be considerable in individual sections, the error is as likely to be positive as negative, and in the long run the error will not be large and generally will be much less than would result by the neglect of any prismoidal correction.

83. True prismoidal correction for irregular prismoids. As intimated in § 82, each cross-section should be assumed to have the same number of sides as the adjacent cross-section when computing the prismoidal correction. This being done, it permits the division of the whole prismoid into elementary triangular prismoids, the dimensions of the bases of which being given in each case by a vertical distance above grade line and by the horizontal distance between two adjacent breaks. The summation of the prismoidal corrections for each of the elementary triangular prismoids will give the true prismoidal correction. Assuming for an example the cross-section of Fig. 44, with a cross-section of the same number of sides, and with dimensions

similarly indicated, for the other end, the prismoidal correction becomes (see Eq. 46)

$$\frac{l}{12} \left[(h'_i - h''_i)[(x''_i - y''_i) - (x'_i - y'_i)] + (k'_i - k''_i)[(x''_i - y''_i) - (x'_i - y'_i)] \right. \\ + (k'_i - k''_i)(y''_i - y'_i) + (d' - d'')(y''_i - y'_i) + (d' - d'')(z''_r - z'_r) \\ + (j'_r - j''_r)(z''_r - z'_r) + (j'_r - j''_r)[(y''_r - z''_r) - (y'_r - z'_r)] \\ + (k'_r - k''_r)[(y''_r - z''_r) - (y'_r - z'_r)] \\ + (k'_r - k''_r)[(x''_r - y''_r) - (x'_r - y'_r)] + (h'_r - h''_r)[(x''_r - y''_r) - (x'_r - y'_r)] \\ \left. - (h'_i - h''_i) \left[\left(x''_i - \frac{b}{2} \right) - \left(x'_i - \frac{b}{2} \right) \right] - (h'_r - h''_r) \left[\left(x''_r - \frac{b}{2} \right) - \left(x'_r - \frac{b}{2} \right) \right] \right].$$

Expanding this and collecting terms, of which many will cancel, we obtain

$$\text{Pris. Corr.} = \frac{l}{12} \left[(x''_i - x'_i)(k'_i - k''_i) + (y''_i - y'_i)[(d' - h'_i) - (d'' - h''_i)] \right. \\ + (x''_r - x'_r)(k'_r - k''_r) + (y''_r - y'_r)[(j'_r - h'_r) - (j''_r - h''_r)] \\ \left. + (z''_r - z'_r)[(d' - k'_r) - (d'' - k''_r)] \right]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (62)$$

By comparing this equation with Eq. 61 a remarkable coincidence in the law of formation may be seen, which enables this formula to be written by mere inspection and to be applied numerically with a minimum of labor from the computations for end areas, as will be shown (§ 84) by a numerical example. For each term in Eq. 61, as, for example, $y_r(j_r - h_r)$, there is a correction term in Eq. 62 of the form

$$(y''_r - y'_r)[(j'_r - h'_r) - (j''_r - h''_r)].$$

Each one of these terms (y''_r , y'_r , $(j'_r - h'_r)$, and $(j''_r - h''_r)$) has been previously used in finding the end areas and has its place in the computation sheet. The summation of the products of these differences times a constant gives the total true prismoidal correction in cubic yards for the whole prismoid considered.


The *constant* is the same as that computed in § 78, i.e., $\frac{25}{81}$.

84. Numerical example; irregular sections; volume, with true prismoidal correction.

Sta.	Center { cut or fill.	Left.			Right.	
19	0.6c	$\frac{3.6c}{14.4}$	$(\frac{2.3c}{8.2})$	$(\frac{1.8c}{6.0})$	$\frac{0.1c}{4.2}$	$\frac{0.4c}{9.6}$
18	2.3c	$\frac{4.2c}{15.3}$	$\frac{6.8c}{8.4}$	$\frac{3.2c}{5.2}$	$(\frac{1.9c}{3.6})$	$\frac{1.2c}{10.8}$
17	7.6c	$\frac{8.2c}{21.8}$	$\frac{10.2c}{17.4}$	$\frac{8.0c}{6.1}$	$(\frac{5.8c}{8.0})$	$\frac{4.2c}{15.3}$
+ 42	10.2c	$\frac{12.2c}{27.3}$	$(\frac{12.3c}{22.0})$	$\frac{12.6c}{8.2}$	$\frac{6.2c}{7.5}$	$\frac{8.4c}{21.6}$
16	6.8c	$\frac{8.9c}{22.4}$		$\frac{7.6c}{12.0}$	$\frac{3.2c}{4.1}$	$\frac{2.6c}{12.9}$

Roadbed 18 feet wide in cut; slope 1½ to 1.

The figures in the bracket $(\frac{12.3c}{22.0})$ mean that it was noted in the field that the break, indicated at Sta. 17 as being 17.4 to the left, ran out at Sta. 16 + 42 at 22.0 to the left. By interpolation between 8.2 and 27.3 the height of this point is *computed* as 12.3. The quantities in the other brackets are obtained similarly. These quantities are only used when the computation of the true prismoidal correction is desired. They are not needed in computing the volume by averaging end areas, nor are they used at all if the prismoidal correction is to be obtained by assuming (*for this purpose*) the ground to be *three-level* ground.

In the tabular form on page 98 the figures within the braces () are NOT used in computing the volume, but are only used to obtain the *differences* of widths or heights with which to compute the *true* prismoidal correction. It may be noted, as a check, that the volume, computed from these figures in the braces, is the same as that computed from the other figures.

VOLUME OF IRREGULAR PRISMOID, WITH TRUE PRISMOIDAL CORRECTION.

Sta.	Width.	Height.	Yards.		True pris. corr.		
					$w'' - w'$	$h' - h''$	Yards.
16	L $\left[\begin{smallmatrix} 22.4 \\ 12.0 \\ 12.9 \\ 4.1 \\ 9.0 \end{smallmatrix}\right]$ R	7.6	158				
		— 2.1	— 23				
		3.2	40				
		4.2	16				
		11.5	96				
+ 42	L $\left[\begin{smallmatrix} 27.3 \\ 8.2 \end{smallmatrix}\right]$ L $\left\{\begin{smallmatrix} 27.3 \\ 22.0 \\ 8.2 \\ 21.6 \\ 7.5 \\ 9.0 \end{smallmatrix}\right.$ R	12.6	319		+ 4.9	— 5.0	— 7
		— 2.0	— 15		— 3.8	— 0.1	0
		12.3					
		0.4					
		— 2.1					
		6.2	124		+ 8.7	— 3.0	— 8
		1.8	13		+ 3.4	+ 2.4	+ 3
		20.6	172	378			(— 5)
17	L $\left[\begin{smallmatrix} 21.3 \\ 17.4 \\ 6.1 \\ 15.3 \\ 8.0 \\ 15.3 \\ 9.0 \end{smallmatrix}\right]$ R	10.2	201		— 6.0	+ 2.1	— 4
		— 0.2	— 3		— 4.6	+ 0.6	— 1
		— 2.6	— 14		— 2.1	+ 0.5	0
		5.8			— 6.8	+ 0.4	— 1
		3.4			+ 0.5	— 1.6	0
		7 6	107				
		12.4	103	584			(— 3)
18	L $\left[\begin{smallmatrix} 15.8 \\ 8.4 \\ 5.2 \\ 10.8 \\ 10.8 \\ 3.6 \\ 9.0 \end{smallmatrix}\right]$ R	6.8	95		— 6.0	+ 3.4	— 6
		— 1.0	— 7		— 9.0	+ 0.8	— 2
		— 4.5	— 22		— 0.9	+ 1.9	— 1
		2.3	23		— 4.5	+ 5.3	— 7
		1.9					
		1.1					
		5.4	45	528			(— 16)
19	L $\left[\begin{smallmatrix} 14.4 \\ 14.4 \\ 8.2 \\ 6.0 \\ 9.6 \\ 4.2 \\ 9.0 \end{smallmatrix}\right]$ R	0.6	8		— 0.9	+ 4.5	— 1
		2.3			— 0.2	+ 0.8	0
		— 1.8			+ 0.8	— 2.8	— 1
		— 1.7			— 1.2	+ 1.8	— 1
		0.1	1		+ 0.6	+ 0.9	0
		0.2	1				
		4.0	33	177			(— 3)
Approx. vol. = 1667 — 27							
True pris. corr. = — 27							
True volume = 1640 cubic yards							

The figures within each brace (or bracket) constitute a group which must be used in connection with a group which has the same number of points, on the same side of the center, in the *next* cross-section, previous or succeeding. In the column of

“Yards” under “True pris. corr.,” we have, for example, $(-5) = \frac{42}{100}(-7 + 0 - 8 + 3)$.

85. Volume of irregular prismoid, with approximate prismoidal correction. If the prismoidal correction is obtained approximately, by the method outlined in § 82, the process will be as shown in the tabular form. Not only is the numerical work considerably less than the exact method, but the discrepancy in cubic yards is almost insignificant.

Sta.	Width.	Height.	Yards.		Cen. Height.	Total width.	$d'-d''$	$w''-w'$	Approx. pris. corr.
16	22.4	7.6	158		+ 6.8	35.3			
	12.0	- 2.1	- 23						
	12.9	3.2	40						
	4.1	4.2	16						
	9.0	11.5	96						
+ 42	27.3	12.6	319		+ 10.2	48.9	- 3.4	+ 13.6	- 14
	8.2	- 2.0	- 15						
	21.6	6.2	124						
	7.5	1.8	13						
	9.0	20.6	172	378					
17	21.3	10.2	201		+ 7.6	36.6	+ 2.6	- 12.3	- 10
	17.4	- 0.2	- 8						
	6.1	- 2.6	- 14						
	15.3	7.6	107						
	9.0	12.4	103	584					
18	15.3	6.8	95		+ 2.3	26.1	+ 5.3	- 10.5	- 17
	8.4	- 1.0	- 7						
	5.2	- 4.5	- 22						
	10.8	2.3	23						
	9.0	5.4	45	528					
19	14.4	0.6	8		+ 0.6	24.0	+ 1.7	- 2.1	- 1
	9.6	0.1	1						
	4.2	0.2	1						
	9.0	4.0	33	177					

Approx. volume = 1667

Approx. pris. corr. = - 30

Corrected volume = 1637 cubic yards

86. Illustration of value of approximate rules. The accompanying tabulation shows that when the volume of an irregular prismoid is computed by averaging end areas and is corrected by considering the ground as three-level ground (*for the pur-*

poses of the correction only), the error for the different sections is sometimes positive and sometimes negative, and in this case

Sections.	True volume.	Approx. vol. by averaging end areas.	Difference or true pris. corr.	Approx. pris. corr. on basis of three-level ground.	Error.	Approx. vol., computed from center and side heights only.	Error.
16.....16 + 42	878	878	- 5	- 6	- 1	896	+ 23
16 + 42...17	581	584	- 3	- 6	- 3	577	- 4
17.....18	512	528	- 16	- 17	- 1	463	- 49
18 .....19	174	177	- 3	- 1	+ 2	147	- 27
	1640	1667	- 27	- 30	- 3	1568	- 57

amounts to only 3 yards in 1640—less than $\frac{1}{50}$ of 1%. If the prismoidal correction had been neglected, the error would have been 27 yards—nearly 2%. The approximate results are here *too large* for each section—as is usually the case. If points between the center and slope stakes are omitted and the volume computed as if the ground were *three-level* ground, the error is quite large in individual sections, but the errors are both positive and negative and therefore compensating.

87. Cross-sectioning irregular sections. The prismoids considered have *straight* lines joining corresponding points in the two cross-sections. The center line must be straight between two cross-sections. If a ridge or valley is found lying diagonally across the roadbed, a cross-section *must* be interpolated at the lowest (or highest) point of the profile. Therefore a “break” at any section cannot be said to run out at the other section on the *opposite* side of the center. It must run out on the *same* side of the center or possibly *at* the center. Very frequently complicated cross-sectioning may be avoided by computing the volume, by some special method, of a mound or hollow when the ground is comparatively regular except for the irregularity referred to.

88. Side-hill work. When the natural slope cuts the roadbed there is a necessity for both cut and fill at the same cross-section. When this occurs the cross-sections of both cut and fill are often so nearly triangular that they may be considered as such without

great error, and the volumes may be computed separately as triangular prismoids without adopting the more elaborate form of computation so necessary for complicated irregular sections. When the ground is too irregular for this the best plan is to follow the uniform system. In computing the cut, as in Fig. 53,

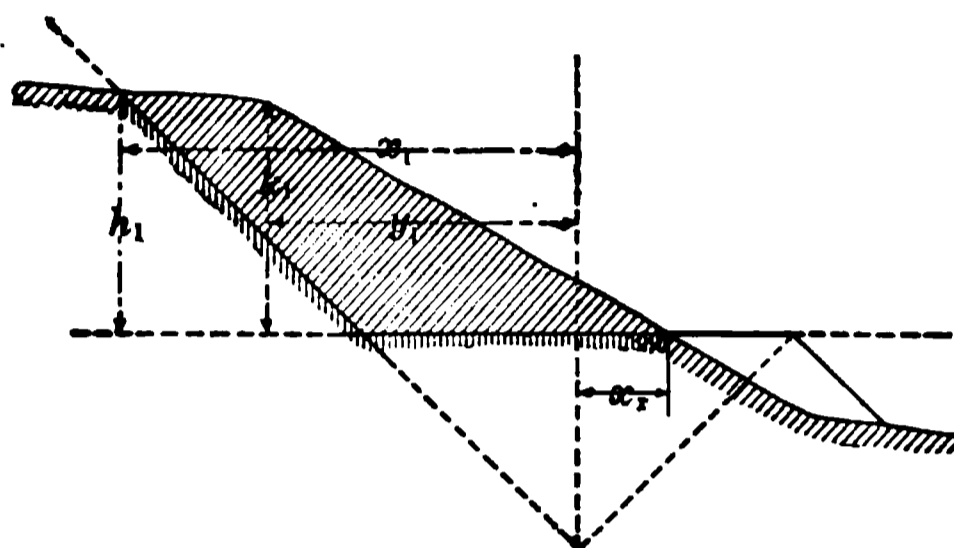


FIG. 53.

the left side would be as usual; there would be a small center cut and an ordinate of zero at a short distance to the right of the center. Then, *ignoring the fill*, and applying Eq. 61 strictly, we have two terms for the left side, one for the right, and the term involving $\frac{1}{2}b$, which will be $\frac{1}{2}bh_1$ in this case, since $h_r = 0$, and the equation becomes

$$\text{Area} = \frac{1}{2}[x_1h_1 + y_1(d - h_1) + x_2d + \frac{1}{2}bh_1].$$

The area for fill may also be computed by a strict application

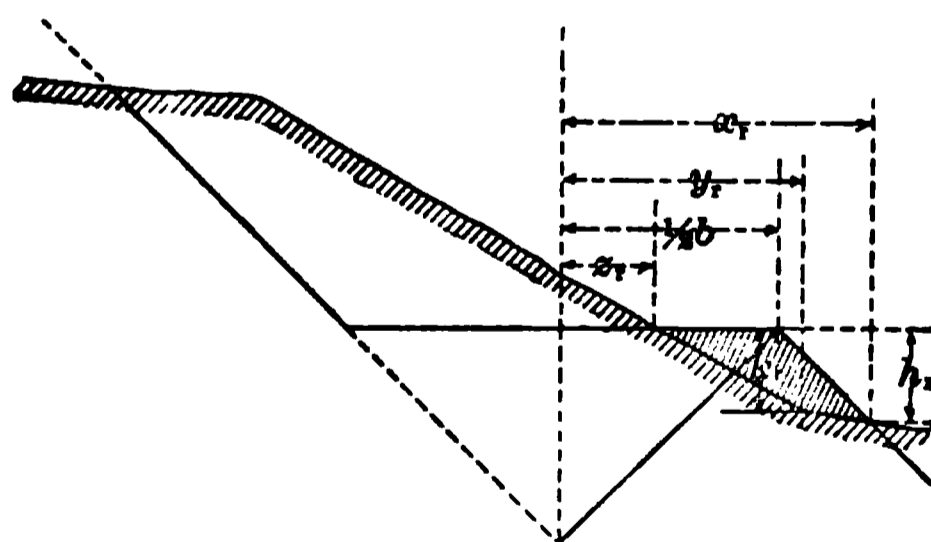


FIG. 54.

of Eq. 61, but for Fig. 54 all distances for the left side are zero and the elevation for the first point out is zero. d also must be

considered as zero. Following the rule, § 81, literally, the equation becomes

$$\text{Area}_{\text{FIN}} = \frac{1}{2}[x_r k_r + y_r(o - h_r) + z_r(o - k_r) + \frac{1}{2}b(o + h_r)],$$

which reduces to

$$\frac{1}{2}[x_r k_r - y_r h_r - z_r k_r + \frac{1}{2}b h_r].$$

(Note that x_r , h_r , etc., have different significations and values in this and in the preceding paragraphs.) The “terminal pyramids” illustrated in Fig. 40 are instances of side-hill work for very short distances. Since side-hill work always implies *both* cut and fill at the same cross-section, whenever either the cut or fill disappears and the earthwork becomes wholly cut or wholly fill, that point marks the end of the “side-hill work,” and a cross-section should be taken at this point.

89. Borrow-pits. The cross-sections of borrow-pits will vary not only on account of the undulations of the surface of the

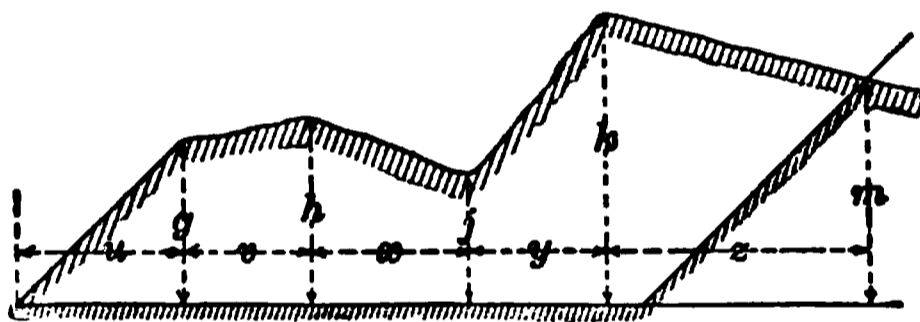


FIG. 55.

ground, but also on the sides, according to whether they are made by widening a convenient cut (as illustrated in Fig. 55) or simply by digging a pit. The sides should always be properly sloped and the cutting made cleanly, so as to avoid unsightly roughness. If the slope ratio on the right-hand side (Fig. 55) is s , the area of the triangle is $\frac{1}{2}sm^2$. The area of the section is $\frac{1}{2}[ug + (g + h)v + (h + j)x + (j + k)y + (k + m)z - sm^2]$. If all the horizontal measurements were referred to one side as an origin, a formula similar to Eq. 61 could readily be developed, but little or no advantage would be gained on account of any simplicity of computation. Since the *exact* volume of the earth borrowed is frequently necessary, the prismoidal correc-

tion should be computed; and since such a section as Fig. 55 does not even approximate to a three-level section, the method suggested in § 82 cannot be employed. It will then be necessary to employ the exact method, § 83, by dividing the volume into triangular prismoids and taking the summation of their corrections, found according to the general method of § 71.

90. Correction for curvature. The volume of a solid, generated by revolving a plane area about an axis lying in the plane but outside of the area, equals the product of the given area times the length of the path of the center of gravity of the area. If the centers of gravity of all cross-sections lie in the center of the road, where the length of the road is measured, there is absolutely no necessary correction for curvature. If all the cross-sections in any given length were exactly the same and therefore had the same eccentricity, the correction for curvature would be very readily computed according to the above principle. But when both the areas and the eccentricities vary from point to point, as is generally the case, a theoretically exact solution is quite complex, both in its derivation and application. Suppose, for simplicity, a curved section of the road, of uniform cross-sections and with the center of gravity of every cross-section at the same distance e from the center line of the road. The length of the path of the center of gravity will be to the length of the center line as $R \pm e : R$. Therefore we have *True vol. : nominal vol. :: $R \pm e : R$* .

$\therefore \text{True vol.} = lA \frac{R \pm e}{R}$ for a volume of uniform area and eccentricity. For any other area and eccentricity we have, similarly, $\text{True vol.}' = lA' \frac{R \pm e'}{R}$. This shows that the effect of curvature is the same as increasing (or diminishing) the area by a quantity depending on the area and eccentricity, the increased (or diminished) area being found by multiplying the actual area by the ratio $\frac{R \pm e}{R}$. This being independent of the value of l , it is true for infinitesimal lengths. If the eccen-

tricity is assumed to vary uniformly between two sections, the *equivalent area* of a cross-section located midway between the

two end cross-sections would be $A_m \frac{\left(R \pm \frac{e' + e''}{2}\right)}{R}$. Therefore the volume of a solid which, when straight, would be $\frac{l}{6}(A' + 4A_m + A'')$, would then become

$$\text{True vol.} = \frac{l}{6R} \left[A'(R \pm e') + 4A_m \left(R \pm \frac{e' + e''}{2} \right) + A''(R \pm e'') \right].$$

Subtracting the nominal volume (the true volume when the prismoid is straight), the

$$\text{Correction} = \pm \frac{l}{6R} \left[(A' + 2A_m)e' + (2A_m + A'')e'' \right]. \quad (63)$$

Another demonstration of the same result is given by Prof. C. L. Crandall in his "Tables for the Computation of Railway and other Earthwork," in which is obtained by calculus methods the summation of elementary volumes having variable areas with variable eccentricities. The exact application of Eq. (63) requires that A_m be known, which requires laborious computations, but no error worth considering is involved if the equation is written approximately

$$\text{Curv. corr.} = \frac{l}{2R} (A'e' + A''e''), \quad . \quad . \quad . \quad (64)$$

which is the equation generally used. The approximation consists in assuming that the difference between A' and A_m equals the difference between A_m and A'' but with opposite sign. The error due to the approximation is always utterly insignificant.

91. Eccentricity of the center of gravity. The determination of the true positions of the centers of gravity of a long series of irregular cross-sections would be a very laborious operation, but fortunately it is generally sufficiently accurate to

consider the cross-sections as three-level ground, or, for side-hill work, to be triangular, *for the purpose of this correction*. The

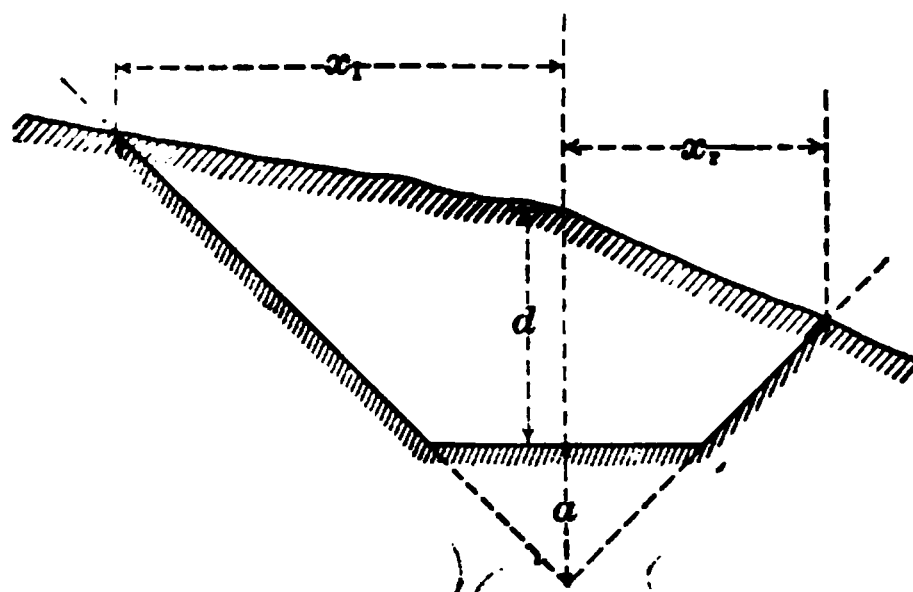


FIG. 56.

eccentricity of the cross-section of Fig. 56 (including the grade triangle) may be written

$$e = \frac{\frac{(a+d)x_l}{2} \frac{x_l}{3} - \frac{(a+d)x_r}{2} \frac{x_r}{3}}{\frac{(a+d)x_l}{2} + \frac{(a+d)x_r}{2}} = \frac{1}{3} \frac{x_l^2 - x_r^2}{x_l + x_r} = \frac{1}{3}(x_l - x_r). \quad (65)$$

The side toward x_r being considered positive in the above demonstration, if $x_r > x_l$, e would be negative, i.e., the center of gravity would be on the left side. Therefore, for three-level ground, the correction for curvature (see Eq. 64) may be written

$$\text{Correction} = \frac{l}{6R} [A'(x_l' - x_r') + A''(x_l'' - x_r'')].$$

Since the approximate volume of the prismoid is

$$\frac{l}{2}(A + A') = \frac{l}{2}A' + \frac{l}{2}A'' = V' + V'',$$

in which V' and V'' represent the number of cubic yards corresponding to the area at each station, we may write

$$\text{Corr. in cub. yds.} = \frac{1}{3R} [V'(x_l' - x_r') + V''(x_l'' - x_r'')]. \quad (66)$$

It should be noted that the value of e , derived in Eq. 65, is the eccentricity of the whole area including the triangle under the roadbed. The eccentricity of the true area is greater than this and equals

$$e \times \frac{\text{true area} + \frac{1}{2}ab}{\text{true area}} = e_1.$$

The required quantity ($A'e'$ of Eq. 64) equals $\text{true area} \times e_1$, which equals $(\text{true area} + \frac{1}{2}ab) \times e$. Since the value of e is very simple, while the value of e_1 would, in general, be a complex quantity, it is easier to use the simple value of Eq. 65 and add $\frac{1}{2}ab$ to the area. Therefore, in the case of three-level ground the subtractive term $\frac{2}{3}\frac{1}{4}ab$ (§ 78) should *not* be subtracted in computing this correction. For irregular ground, when computed by the method given in §§ 81 and 82, which does not involve the grade triangle, a term $\frac{2}{3}\frac{1}{4}ab$ must be *added* at every station when computing the quantities V' and V'' for Eq. 66.

It should be noted that the factor $1 \div 3R$, which is constant for the length of the curve, may be computed with all necessary accuracy and without resorting to tables by remembering that

$$R = \frac{5730}{\text{degree of curve}}.$$

Since it is useless to attempt the computation of railroad earthwork closer than the nearest cubic yard, it will frequently be possible to write out all curvature corrections by a simple mental process upon a mere inspection of the computation sheet. Eq. 66 shows that the correction for each station is of the form $\frac{V(x_l - x_r)}{3R}$. $3R$ is generally a large quantity—for a 6° curve

it is 2865. $(x_l - x_r)$ is generally small. It may frequently be seen by inspection that the product $V(x_l - x_r)$ is roughly twice or three times $3R$, or perhaps less than half of $3R$, so that the corrective term for that station may be written 2, 3, or 0 cubic yards, the fraction being disregarded. For much larger absolute

amounts the correction must be computed with a correspondingly closer percentage of accuracy.

The algebraic sign of the curvature correction is best determined by noting that the center of gravity of the cross-section is on the right or left side of the center according as x_r is greater or less than x_l , and that the correction is *positive* if the center of gravity is on the *outside* of the curve, and *negative* if on the *inside*.

It is frequently found that x_l is uniformly greater (or uniformly less) than x_r throughout the length of the curve. Then the curvature correction for each station is uniformly positive or negative. But in irregular ground the center of gravity is apt to be irregularly on the outside or on the inside of the curve, and the curvature correction will be correspondingly positive or negative. If the curve is to the *right*, the correction will be positive or negative according as $(x_l - x_r)$ is positive or negative; if the curve is to the *left*, the correction will be positive or negative according as $(x_r - x_l)$ is positive or negative. Therefore when computing curves to the *right* use the form $(x_l - x_r)$ in Eqs. 66 and 68; when computing curves to the *left* use the form $(x_r - x_l)$ in these equations; the algebraic sign of the correction will then be strictly in accordance with the results thus obtained.

92. Center of gravity of side-hill sections. In computing the

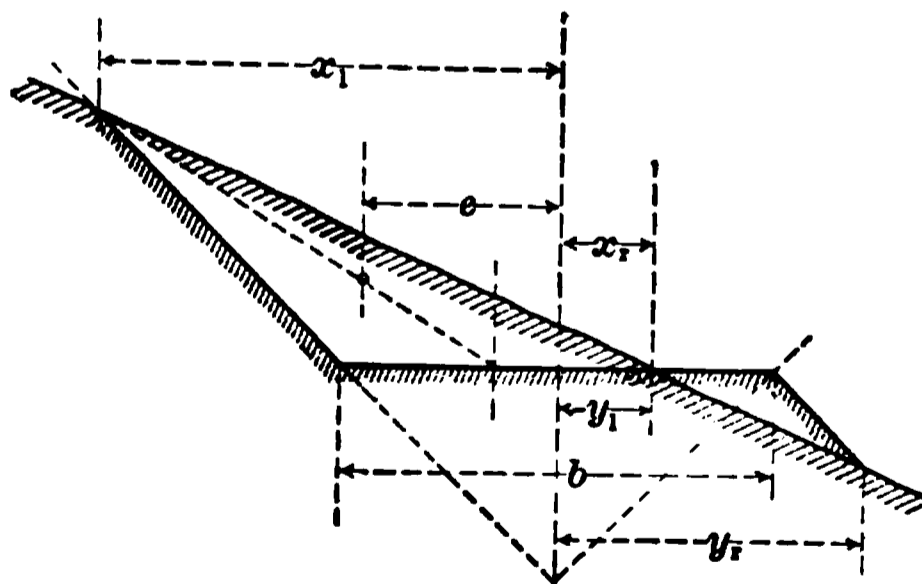


FIG. 57.

correction for side-hill work the cross section would be treated as triangular unless the error involved would evidently be too

which reduces to

$$e = -\frac{1}{3} \left[\frac{b}{2} + y_l + y_r \right]. \quad . \quad . \quad . \quad . \quad . \quad (69)$$

As the algebraic signs tend to create confusion in these formulæ, it is more simple to remember that for a triangle lying on *both* sides of the center e is always numerically equal to $\frac{1}{3} \left[\frac{b}{2} + (x_l \sim x_r) \right]$, and for a triangle entirely on one side, e is numerically equal to $\frac{1}{3} \left[\frac{b}{2} + \text{the numerical sum of the two distances out} \right]$. The algebraic sign of e is readily determinable as in § 91.

93. Example of curvature correction. Assume that the fill in § 78 occurred on a 6° curve to the *right*. $\frac{1}{3R} = \frac{1}{2865}$. The quantities 210, 507, etc., represent the quantities V' , V'' , etc., since they include in each case the 61 cubic yards due to the grade prism. Then

$$\frac{V(x_l \sim x_r)}{3R} = \frac{210(22.9 - 8.2)}{2865} = \frac{3101.7}{2865} = + 1.$$

The sign is plus since the center of gravity of the cross-section is on the left side of the center and the road curves to the right, thus making the true volume larger. For Sta. 18 the correction, computed similarly, is $+ 3$, and the correction for the whole section is $1 + 3 = 4$. For Sta. 18 $+ 40$ the correction is computed as 6 yards. Therefore, for the 40 feet, the correction is $\frac{40}{100}(3 + 6) = 3.6$, which is called 4. Computing the others similarly we obtain a total correction of $+ 16$ cubic yards.

94. Accuracy of earthwork computations. The preceding methods give the *precise volume* (except where approximations are distinctly admitted) of the prismoids which are *supposed* to represent the volume of the earthwork. To appreciate the accuracy necessary in cross-sectioning to obtain a given accuracy

in volume, consider that a fifteen-foot length of the cross-section, which is assumed to be straight, really sags 0.1 foot, so that the cross-section is in error by a triangle 15 feet wide and 0.1 foot high. This sag 0.1 foot high would hardly be detected by the eye, but in a length of 100 feet in each direction it would make an error of volume of 1.4 cubic yards in *each* of the two prismoids, assuming that the sections at the other ends were perfect. If the cross-sections at both ends of a prismoid were in error by this same amount, the volume of that prismoid would be in error by 2.8 cubic yards if the errors of area were both plus or both minus. If one were plus and one minus, the errors would neutralize each other, and it is the compensating character of these errors which permits any confidence in the results as obtained by the usual methods of cross-sectioning. It demonstrates the utter futility of attempting any closer accuracy than the nearest cubic yard. It will thus be seen that if an error really exists at *any* cross-section it involves the prismoids on *both* sides of the section, even though all the other cross-sections are perfect. As a further illustration, suppose that cross-sections were taken by the method of slope angle and center depth (§ 73), and that a cross-section, assumed as uniform, sags 0.4 foot in a width of 20 feet. Assume an equal error (of same sign) at the other end of a 100-foot section. The error of volume for that one prismoid is 38 cubic yards.

The computations further assume that the warped surface, passing through the end sections, coincides with the surface of the ground. Suppose that the cross-sectioning had been done with mathematical perfection; and, to assume a simple case, suppose a sag of 0.5 foot between the sections, which causes an error equal to the volume of a pyramid having a base of 20 feet (in each cross-section) times 100 feet (between the cross-sections) and a height of 0.5 foot. The volume of this pyramid is $\frac{1}{3}(20 \times 100) \times 0.5 = 333$ cub. ft. = 12 cub. yds. And yet this sag or hump of 6 inches would generally be utterly unnoticed, or at least disregarded.

When the ground is very rough and broken it is sometimes

practically impossible, even with frequent cross-sections, to locate warped surfaces which will closely coincide with all the sudden irregularities of the ground. In such cases the computations are necessarily more or less approximate and dependence must be placed on the compensating character of the errors.

95. Approximate computations from profiles. As a means of comparing the relative amounts of earthwork on two or more proposed routes which have been surveyed by preliminary surveys, it will usually be sufficiently accurate to compare the *areas* of cutting (assuming that the cut and fill are approximately balanced) as shown by the several profiles. The errors involved may be large in individual cases and for certain small sections, but fortunately the errors (in comparing two lines) will be largely compensated. The errors are much larger on side-hill work than when the cross-sections are comparatively level. The errors become large when the depth of cut or fill is very great. If the lines compared have the same general character as to the slope of the cross-sections, the proportion of side-hill work, and the average depth of cut or fill, the error involved in considering their relative volumes of cutting to be as the relative areas of cutting on the profiles (obtained perhaps by a planimeter) will probably be small. If the volume in each case is computed by assuming the sections as *level*, with a depth equal to the center cut, the error involved will depend only on the amount of side-hill work and the degree of the slope. If these features are about the same on the two lines compared, the error involved is still less.

FORMATION OF EMBANKMENTS.

96. Shrinkage of earthwork. The evidence on this subject as to the amount of shrinkage is very conflicting, a fact which is probably due to the following causes:

1. The various kinds of earthy material act very differently as respects shrinkage. There has been but little uniformity in the *classification of earths* in the tests and experiments that have been made.

2. Very much depends on the *method* of forming an embankment (as will be shown later). Different reports have been based on different methods—often without mention of the method.

3. An embankment requires considerable *time* to shrink to its final volume, and therefore much depends on the time elapsed between construction and the measurement of what is supposed to be the settled volume.

P. J. Flynn quotes some experiments (*Eng. News*, May 1, 1886) made in India in which pits were dug, having volumes of 400 to 600 cubic feet. The material, when piled into an embankment, measured largely in excess of the original measurement—as is the universal experience. The pits were refilled with the same material. As the rains, very heavy in India, settled the material in the pits, more was added to keep the pits full. Even after the rainy season was over, there was in every case material in excess. This would seem to indicate a permanent *expansion*, although it is possible that the observations were not continued for a sufficient time to determine the final settled volume.

On the contrary, notes made by Mr. Elwood Morris many years ago on the behavior of embankments of several thousand cubic yards, formed in layers by carts and scrapers, one winter intervening between commencement and completion, showed in each case a permanent *contraction* averaging about 10%.

All authorities agree that rockwork *expands* permanently when formed into an embankment, but the percentages of expansion given by different authorities differ even more than with earth—varying from 8 to 90%. Of course this very large range in the coefficient is due to differences in the character of the rock. The softer the rock and the closer its similarity to earth, the less will be its expansion. On account of the conflicting statements made, and particularly on account of the influence of methods of work, but little confidence can be felt in any given coefficient, especially when given to a fraction of a per

cent, but the consensus of American practice seems to average about as follows:

Permanent contraction of earth.....	about 10%
“ expansion of rock.....	40 to 60%

These values for rock should be materially reduced, according to judgment, when the rock is soft and liable to disintegrate. The hardest rocks, loosely piled, may occasionally give even higher results. The following is given by several authors as the permanent contraction of several grades of earth:

Gravel or sand.....	about 8%
Clay.....	“ 10%
Loam.....	“ 12%
Loose vegetable surface soil.....	“ 15%

It may be noticed from the above table that the harder and cleaner the material the less is the contraction. Perfectly clean gravel or sand would not probably change volume appreciably. The above coefficients of shrinkage and expansion may be used to form the following convenient table.

Material.	To make 1000 cubic yards of embankment will require	1000 cubic yards measured in excavation will make
Gravel or sand.....	1087 cubic yards	920 cubic yards
Clay.....	1111 “ “	900 “ “
Loam.....	1136 “ “	880 “ “
Loose vegetable soil.....	1176 “ “	850 “ “
Rock, large pieces.....	714 “ “	1400 “ “
“ small “	625 “ “	1600 “ “
	measured in excavation	of embankment.

97. Allowance for shrinkage. On account of the initial expansion and subsequent contraction of earth, it becomes necessary to form embankments higher than their required ultimate form in order to allow for the subsequent shrinkage. As the shrinkage appears to be all vertical (practically), the embankment must be formed as shown in Fig. 58. The effect

of shrinkage should not be confounded with that of slipping of the sides, which is especially apt to occur if the embankment is subjected to heavy rains very soon after being formed, and also when the embankments are originally steep. It is often difficult

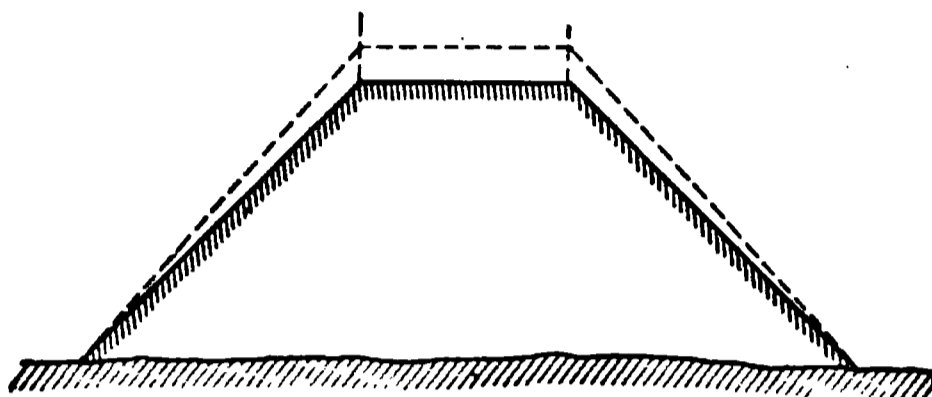


FIG. 58.

to form an embankment at a slope of 1 : 1 which will not slip more or less before it hardens.

Very high embankments shrink a greater percentage than lower ones. Various rules giving the relation between shrinkage and height have been suggested, but they vary as badly as the suggested coefficients of contraction, probably for the same causes. As the fact is unquestionable, however, the extra height of the embankment must be varied somewhat as in Fig. 59, which represents a longitudinal section of an embankment.

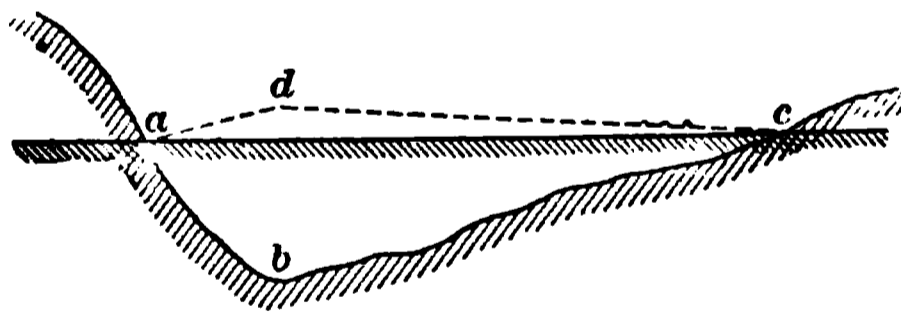


FIG. 59.

As considerable time generally elapses between the completion of the embankment and the actual running of trains, the grade *ad* will generally be nearly flattened down to its ultimate form before traffic commences, but such grades are occasionally objectionable if added to what is already a ruling grade. With some kinds of soil the time required for complete settlement may be as much as two or three years, but, even in such cases, it is

probable that one-half of the settlement will take place during the first six months. The engineer should therefore require the contractor to make all fills about 8 to 15% (according to the material) higher than the profiles call for, in order that subsequent shrinkage may not reduce it to less than the required volume.

98. Methods of forming embankments. When the method is not otherwise objectionable, a high embankment can be formed very cheaply (assuming that carts or wheelbarrows are used) by dumping over the end and building to the full height (or even higher, to allow for shrinkage) as the embankment proceeds. This allows more time for shrinkage, saves nearly all the cost of spreading (see Item 4, § 111), and reduces the cost of roadways (Item 5). Of course this method is especially applicable when the material comes from a place as high as or higher than grade, so that no up-hill hauling is required.

Another method is to spread it in layers two or three feet thick (see Fig. 60), which are made concave upwards to avoid

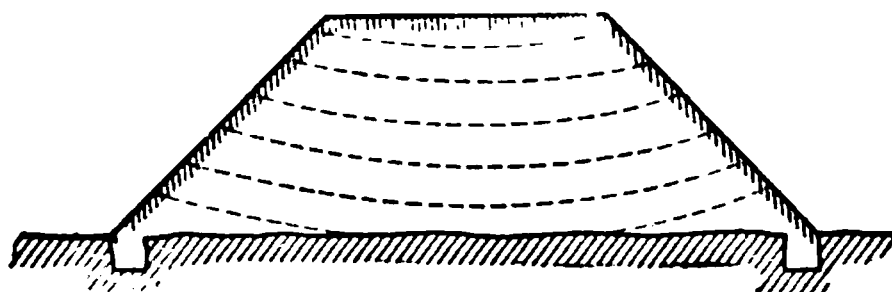


FIG. 60.

possible sliding on each other. Spreading in layers has the advantage of partially ramming each layer, so that the subsequent shrinkage is very small. Sometimes small trenches are dug along the lines of the toes of the embankment. This will frequently prevent the sliding of a large mass of the embankment, which will then require extensive and costly repairs, to say nothing of possible accidents if the sliding occurs after the road is in operation. Incidentally these trenches will be of value in draining the subsoil. When circumstances require an embankment on a hillside, it is advisable to cut out "steps" to prevent a possible sliding of the whole embankment. Merely

ploughing the side-hill will often be a cheaper and sufficiently effective method.

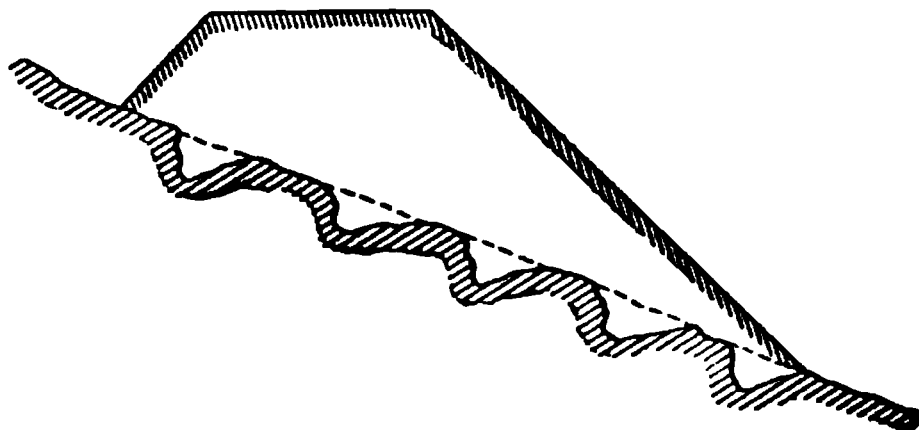


FIG. 61.

Occasionally the formation of a very high and long embankment may be most easily and cheaply accomplished by building a trestle to grade and opening the road. Earth can then be procured where most convenient, perhaps several miles away, loaded on cars with a steam-shovel, hauled by the trainload, and dumped from the cars with a patent unloader. On such a large scale, the cost per yard would be very much less than by ordinary methods—enough less sometimes to more than pay for the temporary trestle, besides allowing the road to be opened for traffic very much earlier, which is often a matter of prime financial importance. It may also obviate the necessity for extensive borrow-pits in the immediate neighborhood of the heavy fill and also utilize material which would otherwise be wasted.

COMPUTATION OF HAUL.

99. Nature of subject. As will be shown later when analyzing the cost of earthwork, the most variable item of cost is that depending on the distance hauled. As it is manifestly impracticable to calculate the exact distance to which every individual cartload of earth has been moved, it becomes necessary to devise a means which will give at least an equivalent of the haulage of all the earth moved. Evidently the *average* haul for any mass of earth moved is equal to the distance from the center of gravity of the excavation to the center of gravity of the embank-

ment formed by the excavated material. As a rough approximation the center of gravity of a cut (or fill) may sometimes be considered to coincide with the center of gravity of that part of the profile representing it, but the error is frequently very large. The center of gravity may be determined by various methods, but the method of the "mass diagram" accomplishes the same ultimate purpose (the determination of the haul) with all-sufficient accuracy and also furnishes other valuable information.

100. Mass diagram. In Fig. 62 let $A'B' \dots G'$ represent a profile and grade line drawn to the usual scales. Assume A'

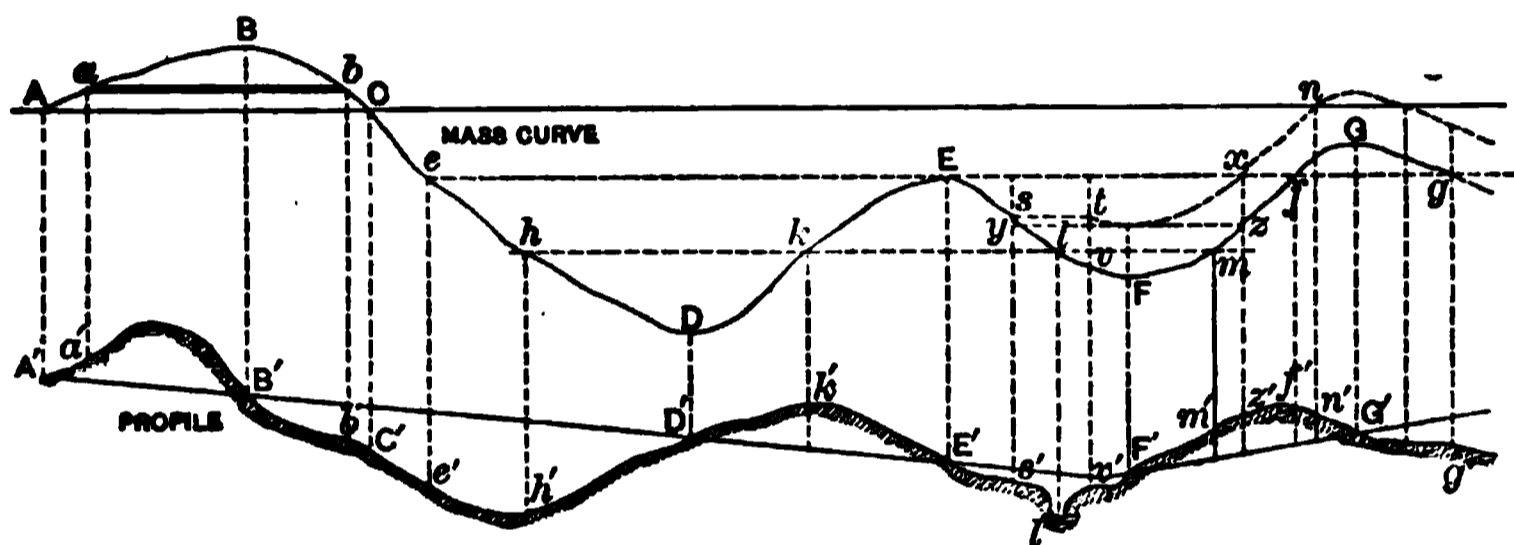


FIG. 62.—MASS DIAGRAM.

to be a point past which no earthwork will be hauled. Above every station point in the profile draw an ordinate which will represent the algebraic sum of the cubic yards of cut and fill (calling cut $+$ and fill $-$) from the point A' to the point considered. In doing this shrinkage must be allowed for by considering how much embankment would actually be made by so many cubic yards of excavation of such material. For example, it will be found that 1000 cubic yards of sand or gravel, measured in place (see § 97), will make about 920 cubic yards of embankment; therefore all cuttings in sand or gravel should be discounted in about this proportion. Excavations in rock should be increased in the proper ratio. In short, all excavations should be valued according to the amount of *settled* embankment that could be made from them. The computations may be made systematically as shown in the tabular form. Place

in the first column a list of the stations; in the second column, the number of cubic yards of cut or fill between each station and the preceding station; in the third and fourth columns, the kind of material and the proper shrinkage factor; in the fifth column, a repetition of the quantities in cubic yards, except that the excavations are diminished (or increased, in the case of rock) to the number of cubic yards of settled embankment which may be made from them. In the sixth column, place the *algebraic sum* of the quantities in the fifth column (calling cuts + and fills -) from the starting-point to the station considered. These algebraic sums at each station will be the ordinates, drawn to some scale, of the mass curve. The scale to be used will depend somewhat on whether the work is heavy or light, but for ordinary cases a scale of 5000 cubic yards per inch may be used. Drawing these ordinates to scale, a curve *A, B, . . . G* may be obtained by joining the extremities of the ordinates.

Sta.	Yards { cut + fill -	Material.	Shrinkage factor.	Yards, reduced for shrinkage.	Ordinate in mass curve.
46	+ 70	.....	.....	.....	0
47	+ 195	Clayey soil	-10 per cent	+ 175	+ 175
48	+1792	" "	-10 "	+1613	+1788
	+ 60	" "	-10 "	+ 553	+2341
49	- 143	.....	.....	- 143	+2198
50	- 906	.....	.....	- 906	+1292
51	-1985	.....	.....	-1985	- 693
52	-1721	.....	.....	-1721	-2414
	+ 80	.....	.....	- 112	-2526
53	+ 177	Hard rock	+60 per cent	+ 283	-2243
	+ 70	" "	+60 "	+ 289	-1954
54	- 52	.....	.....	- 52	-2006
	+ 42	.....	.....	- 71	-2077
55	+ 276	Clayey soil	-10 per cent	+ 249	-1828
56	+1242	" "	-10 "	+1118	- 710
57	+1302	" "	-10 "	+1172	+ 462

101. Properties of the mass curve.

1. The curve will be rising while over cuts and falling while over fills.
2. A tangent to the curve will be horizontal (as at *B, D, E, F*, and *G*) when passing from cut to fill or from fill to cut.

3. When the curve is *below* the “zero line” it shows that material must be drawn *backward* (to the left); and *vice versa*, when the curve is *above* the zero line it shows that material must be drawn *forward* (to the right).

4. When the curve crosses the zero line (as at A and C) it shows (in this instance) that the cut between A' and B' will just provide the material required for the fill between B' and C' , and that no material should be hauled past C' , or, in general, past any intersection of the mass curve and the zero line.

5. If any horizontal line be drawn (as ab), it indicates that the cut and fill between a' and b' will just balance.

6. When the center of gravity of a given volume of material is to be moved a given distance, it makes no difference (at least theoretically) how far each individual load may be hauled or how any individual load may be disposed of. The summation of the products of each load times the distance hauled will be a constant, whatever the method, and will equal the total volume times the movement of the center of gravity. The *average haul*, which is the movement of the center of gravity, will therefore equal the summation of these products divided by the total volume. If we draw two horizontal parallel lines at an infinitesimal distance dx apart, as at ab , the small increment of cut dx at a' will fill the corresponding increment of fill at b' , and this material must be hauled the distance ab . Therefore the product of ab and dx , which is the product of distance times volume, is represented by the area of the infinitesimal rectangle at ab , and the total area ABC represents the summation of volume times distance for all the earth movement between A' and C' . This summation of products divided by the total volume gives the average haul.

7. The horizontal line, tangent at E and cutting the curve at e, f , and g , shows that the cut and fill between e' and E' will just balance, and that a *possible* method of hauling (whether desirable or not) would be to “borrow” earth for the fill between C' and e' , use the material between D' and E' for the

fill between e' and D' , and similarly balance cut and fill between E' and f' and also between f' and g' .

8. Similarly the horizontal line $hklm$ may be drawn cutting the curve, which will show another *possible* method of hauling. According to this plan, the fill between C' and h' would be made by borrowing; the cut and fill between h' and k' would balance; also that between k' and l' and between l' and m' . Since the area $ehDkE$ represents the measure of haul for the earth between e' and E' , and the other areas measure the corresponding hauls similarly, it is evident that the sum of the areas $ehDkE$ and $ElFmf$, which is the measure of haul of all the material between e' and f' , is largely in excess of the sum of the areas hDk , kEl , and lFm , plus the somewhat uncertain measures of haul due to borrowing material for $e'h'$ and wasting the material between m' and f' . Therefore to make the measure of haul a minimum a line should be drawn which will make the sum of the areas between it and the mass curve a minimum. Of course this is not necessarily the cheapest plan, as it implies more or less borrowing and wasting of material, which *may* cost more than the amount saved in haul. The comparison of the two methods is quite simple, however. Since the amount of fill between e' and h' is represented by the *difference* of the ordinates at e and h , and similarly for m' and f' , it follows that the amount to be borrowed between e' and h' will exactly equal the amount wasted between m' and f' . By the first of the above methods the haul is excessive, but is definitely known from the mass diagram, and all of the material is utilized; by the second method the haul is reduced to about one-half, but there is a known quantity in cubic yards wasted at one place and the same quantity borrowed at another. The length of haul necessary for the borrowed material would need to be ascertained; also the haul necessary to waste the other material at a place where it would be unobjectionable. Frequently this is best done by widening an embankment beyond its necessary width. The computation of the relative cost of the above methods will be discussed later (§ 116).

9. Suppose that it were deemed best, after drawing the mass curve, to introduce a trestle between s' and v' , thus saving an amount in fill equal to tv . If such had been the original design, the mass curve would have been a straight horizontal line between s and t and would continue as a curve which would be at all points a distance tv above the curve $vFmzfGg$. If the line Ef is to be used as a zero line, its intersection with the new curve at x will show that the material between E' and z' will just balance if the trestle is used, and that the amount of haul will be measured by the area between the line Ex and the broken line $Estx$. The same computed result may be obtained without drawing the auxiliary curve $txn \dots$ by drawing the horizontal line zy at a distance $xz (= tv)$ below Ex . The amount of the haul can then be obtained by adding the triangular area between Es and the horizontal line Ex , the rectangle between st and Ex , and the irregular area between vFz and $y \dots z$ (which last is evidently equal to the area between tx and $E \dots x$). The disposal of the material at the right of z' would then be governed by the indications of the profile and mass diagram which would be found at the right of g' . In fact it is difficult to decide with the best of judgment as to the proper disposal of material without having a mass diagram extending to a considerable distance each side of that part of the road under immediate consideration.

102. Area of the mass curve. The area may be computed most readily by means of a planimeter, which is capable with reasonable care of measuring such areas with as great accuracy as is necessary for this work. If no such instrument is obtainable, the area may be obtained by an application of "Simpson's rule." The ordinates will usually be spaced 100 feet apart. Select an *even* number of such spaces, leaving, if necessary, one or more triangles or trapezoids at the ends for separate and independent computation. Let $y_0 \dots y_n$ be the ordinates, i.e., the number of cubic yards at each station of the mass curve, or the figures of "column six" referred to in § 100. Let the uniform distance between ordinates ($= 100$ feet) be called 1, i.e.,

one *station*. Then the units of the resulting area will be cubic yards hauled one station. Then the

$$\text{Area} = \frac{1}{2}[y_0 + 4(y_1 + y_3 + \dots y_{(n-1)}) + 2(y_2 + y_4 + \dots y_{(n-2)}) + y_n]. \quad (70)$$

When an ordinate occurs at a substation, the best plan is to ignore it at first and calculate the area as above. Then, if the difference involved is too great to be neglected, calculate the area of the triangle having the extremity of the ordinate at the substation as an apex, and the extremities of the ordinates at the adjacent stations as the ends of the base. This may be done by finding the ordinate at the substation that would be a proportional between the ordinates at the adjacent full stations. Subtract this from the real ordinate (or *vice versa*) and multiply the difference by $\frac{1}{2} \times 1$. An inspection will often show that the correction thus obtained would be too small to be worthy of consideration. If there is more than one substation between two full stations, the corrective area will consist of two triangles and one or more trapezoids which may be similarly computed, if necessary.

When the zero line (Fig. 62) is shifted to eE' , the drop from AC (produced) to E is known in the same units, cubic yards. This constant may be subtracted from the numbers ("column 4," § 100) representing the ordinates, and will thus give, without any scaling from the diagram, the exact value of the modified ordinates.

103. Value of the mass diagram. The great value of the mass diagram lies in the readiness with which different plans for the disposal of material may be examined and compared. When the mass curve is once drawn, it will generally require only a shifting of the horizontal line to show the disposal of the material by any proposed method. The mass diagram also shows the extreme length of haul that will be required by any proposed method of disposal of material. This brings into consideration the "limit of profitable haul," which will be fully discussed in § 116. For the present it may be said that with each method of carrying material there is some limit beyond which the expense

of hauling will exceed the loss resulting from borrowing and wasting. With wheelbarrows and scrapers the limit of profitable haul is comparatively short, with carts and tram-cars it is much longer, while with locomotives and cars it may be several miles. If, in Fig. 62, eE or Ef exceeds the limit of profitable haul, it shows at once that some such line as $hklm$ should be drawn and the material disposed of accordingly.

104. Changing the grade line. The formation of the mass curve and the resulting plans as to the disposal of material are based on the mutual relations of the grade line and the surface profile and the amounts of cut and fill which are thereby implied. If the grade line is altered, every cross-section is altered, the amount of cut and fill is altered, and the mass curve is also changed. At the farther limit of the actual change of the grade line the revised mass curve will have (in general) a different ordinate from the previous ordinate at that point. From that point on, the revised mass curve will be parallel to its former position, and the revised curve may be treated similarly to the case previously mentioned in which a trestle was introduced. Since it involves tedious calculations to determine accurately how much the volume of earthwork is altered by a change in grade line, especially through irregular country, the effect on the mass curve of a change in the grade line cannot therefore be readily determined except in an approximate way. Raising the grade line will evidently increase the fills and diminish the cuts, and *vice versa*. Therefore if the mass curve indicated, for example, either an excessively long haul or the necessity for borrowing material (implying a fill) and wasting material farther on (implying a cut), it would be *possible* to diminish the fill (and hence the amount of material to be borrowed) by lowering the grade line near that place, and diminish the cut (and hence the amount of material to be wasted) by raising the grade line at or near the place farther on. Whether the advantage thus gained would compensate for the possibly injurious effect of these changes on the grade line would require patient investigation. But the method outlined shows how the

mass curve might be used to indicate a possible change in grade line which might be demonstrated to be profitable.

105. Limit of free haul. It is sometimes specified in contracts for earthwork that *all* material shall be entitled to free haul up to some specified limit, say 500 or 1000 feet, and that all material drawn farther than that shall be entitled to an allowance on the *excess* of distance. It is manifestly impracticable to measure the excess for each load, as much so as to measure the actual haul of each load. The mass diagram also solves this problem very readily. Let Fig. 63 represent a pro-

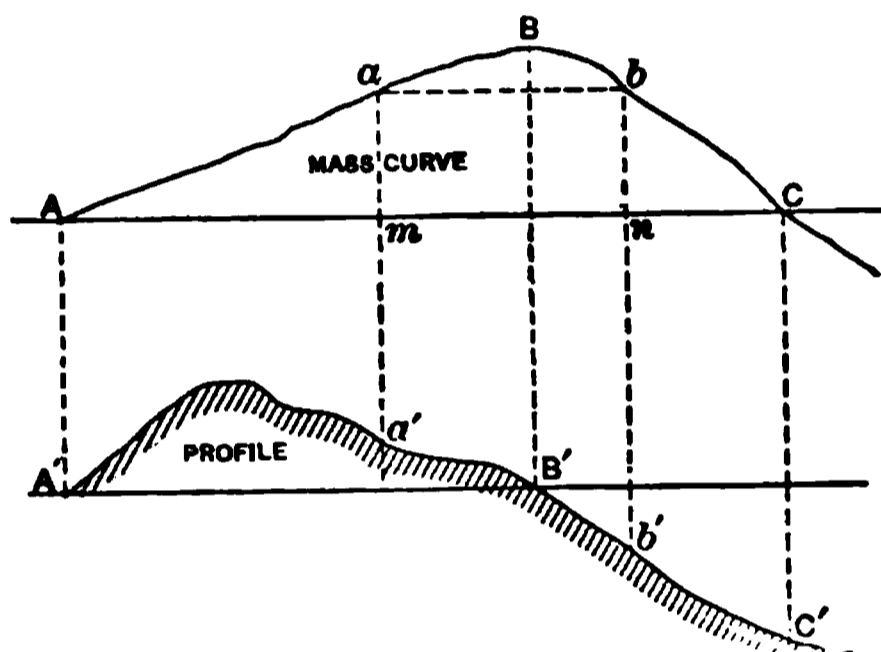


FIG. 63.

file and mass diagram of about 2000 feet of road, and suppose that 800 feet is taken as the limit of free haul. Find two points; a and b , in the mass curve *which are on the same horizontal line* and which are 800 feet apart. Project these points down to a' and b' . Then the cut and fill between a' and b' will just balance, and the cut between A' and a' will be needed for the fill between b' and C' . In the mass curve, the area between the horizontal line ab and the curve aBb represents the haulage of the material between a' and b' , which is all free. The rectangle $abmn$ represents the haulage of the material in the cut $A'a'$ across the 800 feet from a' to b' . This is also free. The sum of the two areas Aam and bnC represents the haulage entitled to an allowance, since it is the summation of the products of cubic yards times the *excess* of distance hauled.

If the amount of cut and fill was symmetrical about the point B' , the mass curve would be a symmetrical curve about the vertical line through B , and the two limiting lines of free haul would be placed symmetrically about B and B' . In general there is no such symmetry, and frequently the difference is considerable. The area $aBbnm$ will be materially changed according as the two vertical lines am and bn , always 800 feet apart, are shifted to the right or left. It is easy to show that the area $aBbnm$ is a *maximum* when ab is horizontal. The minimum value would be obtained either when m reached A or n reached C , depending on the exact form of the curve. Since the position for the minimum value is manifestly unfair, the best definite value obtainable is the maximum, which must be obtained as above described. Since $aBbnm$ is made maximum, the remainder of the area, which is the allowance for overhaul, becomes a minimum. The areas Aam and bCn may be obtained as in § 102. If the whole area $AaBbCA$ has been previously computed, it may be more convenient to compute the area $aBbnm$ and subtract it from the total area.

Since the intersections of the mass curve and the "zero line" mark limits past which no material is drawn, it follows that there will be no allowance for overhaul except where the distance between consecutive intersections of the zero line and mass curve exceeds the limit of free haul.

Frequently all allowances for overhaul are disregarded; the profiles, estimates of quantities, and the required disposal of material are shown to bidding contractors, and they must then make their own allowances and bid accordingly. This method has the advantage of avoiding possible disputes as to the amount of the overhaul allowance, and is popular with railroad companies on this account. On the other hand the facility with which different plans for the disposal of material may be studied and compared by the mass-curve method facilitates the adoption of the most economical plan, and the elimination of uncertainty will frequently lead to a safe reduction of the bid, and so the method is valuable to both the railroad company and the contractor.

ELEMENTS OF THE COST OF EARTHWORK.

(The following analysis of the cost of earthwork follows the general method given in the well-known papers published by Ellwood Morris, C.E., in the Journal of the Franklin Institute in September and October, 1841. Numerous corroborative data have been obtained from various other sources, and also figures on methods not then in vogue.)

106. General divisions of the subject. The variations in the cost of earthwork are caused by the greatly varying conditions under which the work is done, chief among which is character of material, method of carriage, and length of haul. Any general system of computation must therefore differentiate the total cost into such elementary items that all differences due to variations in conditions may be allowed for. The variations due to character of material will be allowed for by an estimate on loose light sandy soil, and also an estimate on the heaviest soils, such as stiff clay and hard-pan. These represent the extremes (excluding rock, which will be treated separately), and the cost of intermediate grades must be estimated by interpolating between the extreme values. The general divisions of the subject will be: *

1. Loosening.
2. Loading.
3. Hauling.
4. Spreading.
5. Keeping roadways in order.
6. Repairs, wear, depreciation, and interest on cost of plant.
7. Superintendence and incidentals.
8. Contractor's profit.

By making the estimates on the basis of \$1 per day for the cost of common labor, it is a simple matter to revise the estimates according to the local price of labor by multiplying the final estimate of cost by the price of labor in dollars per day.

* Trautwine.

107. Item 1. LOOSENING. (a) Ploughs. Very light sandy soils can frequently be shovelled without any previous loosening, but it is generally economical, even with very light material, to use a plough. Morris quotes, as the results of experiments, that a three-horse plough would loosen from 250 to 800 cubic yards of earth per day, which at a valuation of \$5 per day would make the cost per yard vary from 2 cents to 0.6 cent. Trautwine estimates the cost on the basis of two men handling a two-horse plough at a total cost of \$3.87 per day, being \$1 each for the men, 75 c. for each horse, and an allowance of 37 c. for the plough, harness, etc. From 200 to 600 cubic yards is estimated as a fair day's work, which makes a cost of 1.9 c. to 0.65 c. per yard, which is substantially the same estimate as above. Extremely heavy soils have sometimes been loosened by means of special ploughs operated by traction-engines.

(b) Picks. When picks are used for loosening the earth, as is frequently necessary and as is often done when ploughing would perhaps be really cheaper, an estimate* for a fair day's work is from 14 to 60 cubic yards, the 14 yards being the estimate for stiff clay or cemented gravel, and the 60 yards the estimate for the lightest soil that would require loosening. At \$1 per day this means about 7 c. to 1.7 c. per cubic yard, which is about three times the cost of ploughing. Five feet of the face is estimated† as the least width along the face of a bank that should be allowed to enable each laborer to work with freedom and hence economically.

(c) Blasting. Although some of the softer shaly rocks may be loosened with a pick for about 15 to 20 c. per yard, yet rock in general, frozen earth, and sometimes even compact clay is most economically loosened by blasting. The subject of blasting will be taken up later, §§ 117-123.

(d) Steam-shovels. The items of loosening and loading merge together with this method, which will therefore be treated in the next section.

* Trautwine.

† Hurst.

108. Item 2. **LOADING.** (a) **Hand-shovelling.** Much depends on proper management, so that the shovellers need not wait unduly either for material or carts. With the best of management considerable time is thus lost, and yet the intervals of rest need not be considered as entirely lost, as it enables the men to work, while actually loading, at a rate which it would be physically impossible for them to maintain for ten hours. Seven shovellers are sometimes allowed for each cart; otherwise there should be five, two on each side and one in the rear. Economy requires that the number of loads per cart per day should be made as large as possible, and it is therefore wise to employ as many shovellers as can work without mutual interference and without wasting time in waiting for material or carts. The figures obtainable for the cost of this item are unsatisfactory on account of their large disagreements. The following are quoted as the number of cubic yards that can be loaded into a cart by an average laborer in a working day of ten hours, the lower estimate referring to heavy soils, and the higher to light sandy soils: 10 to 14 cubic yards (Morris), 12 to 17 cubic yards (Haskoll), 18 to 22 cubic yards (Hurst), 17 to 24 cubic yards (Trautwine), 16 to 48 cubic yards (Ancelin). As these estimates are generally claimed to be based on actual experience, the discrepancies are probably due to differences of management. If the average of 15 to 25 cubic yards be accepted, it means, on the basis of \$1 per day, 6.7 c. to 4 c. per cubic yard. These estimates apply only to earth. *Rockwork* costs more, not only because it is harder to handle, but because a cubic yard of solid rock, measured in place, occupies about 1.8 cubic yards when broken up, while a cubic yard of earth will occupy about 1.2 cubic yards. Rockwork will therefore require about 50% more loads to haul a given volume, *measured in place*, than will the same nominal volume of earthwork. The above authorities give estimates for loading rock varying from 6.9 c. to 10 c. per cubic yard. The above estimates apply only to the loading of carts or cars with shovels or by hand (loading masses of rock). The

cost of loading wheelbarrows and the cost of scraper work will be treated under the item of hauling.

(b) **Steam-shovels.*** Whenever the magnitude of the work will warrant it there is great economy in the use of steam-shovels. These have a "bucket" or "dipper" on the end of a long beam, the bucket having a capacity varying from $\frac{1}{2}$ to $2\frac{1}{2}$ cubic yards. Steam-shovels handle all kinds of material from the softest earth to shale rock, earthy material containing large boulders, tree-stumps, etc. The capacity of the larger sizes is about 3000 cubic yards in 10 hours. They perform all the work of loosening and loading. Their economical working requires that the material shall be hauled away as fast as it can be loaded, which usually means that cars on a track, hauled by horses or mules, or still better by a locomotive, shall be used. The expenses for a steam-shovel, costing about \$5000, will average about \$1000 per month. Of this the engineer will get \$100; the fireman \$50; the cranesman \$90; repairs perhaps \$250 to \$300; coal, from 15 to 25 tons, cost very variable on account of expensive hauling; water, a very uncertain amount, sometimes costing \$100 per month; about five laborers and a foreman, the laborers getting \$1.25 per day and the foreman \$2.50 per day, which will amount to \$227.50 per month. This gang of laborers is employed in shifting the shovel when necessary, taking up and relaying tracks for the cars, shifting loaded and unloaded cars, etc. In shovelling through a deep cut, the shovel is operated so as to undermine the upper parts of the cut, which then fall down within reach of the shovel, thus increasing the amount of material handled for each new position of the shovel. If the material is too tough to fall down by its own weight, it is sometimes found economical to employ a gang of men to loosen it or even blast it rather than shift the shovel so frequently. Non-condensing engines of 50 horse-power use so much water that the cost of water-supply becomes a serious

* For a thorough treatment of the capabilities, cost, and management of steam-shovels the reader is referred to "Steam-shovels and Steam-shovel Work," by E. A. Hermann. D. Van Nostrand Co., New York.

matter if water is not readily obtainable. The lack of water facilities will often justify the construction of a pipe line from some distant source and the installation of a steam-pump. Hence the seemingly large estimate of \$100 per month for water-supply, although under favorable circumstances the cost may almost vanish. The larger steam-shovels will consume nearly a ton of coal per day of 10 hours. The expense of hauling this coal from the nearest railroad or canal to the location of the cut is often a very serious item of expense and may easily double the cost per ton. Some steam-shovels have been constructed to be operated by electricity obtained from a plant perhaps several miles away. Such a method is especially advantageous when fuel and water are difficult to obtain.

109. Item 3. HAULING. The cost of hauling depends on the number of round trips per day that can be made by each vehicle employed. As the cost of each vehicle is practically the same whether it makes many trips or few, it becomes important that the number of trips should be made a maximum, and to that end there should be as little delay as possible in loading and unloading. Therefore devices for facilitating the passage of the vehicles have a real money value.

(a) **Carts.** The average speed of a horse hauling a two-wheeled cart has been found to be 200 feet per minute, a little slower when hauling the load and a little faster when returning empty. This figure has been repeatedly verified. It means an allowance of one minute for each 100 feet (or "station") of "lead—the lead being the distance the earth is hauled." The time lost in loading, dumping, waiting to load, etc., has been found to average 4 minutes per load. Representing the number of stations (100 feet) of lead by s , the number of loads handled in 10 hours (600 minutes) would be $600 \div (s + 4)$. The number of loads per cubic yard, measured in the bank, is differentiated by Morris into three classes, viz.:

3 loads per cubic yard in descending hauling;
 $3\frac{1}{2}$ " " " " " level hauling; and
 4 " " " " " ascending hauling.

Attempts have been made to estimate the effect of the grade of the roadway by a theoretical consideration of its rate, and of the comparative strength of a horse on a level and on various grades. While such computations are always practicable on a railway (even on a temporary construction track), the traction on a temporary earth roadway is always very large and so very variable that any refinements are useless. On railroad earthwork the hauling is generally nearly level or it is *descending*—forming embankments on low ground with material from cuts in high ground. The only common exception occurs when an embankment is formed from borrow-pits on low ground. One method of allowing for ascending grade is to add to the horizontal distance 14 times the difference of elevation for work with carts and 24 times the difference of elevation for work with wheelbarrows, and use that as the lead. For example, using carts, if the lead is 300 feet and there is a difference of elevation of 20 feet, the lead would be considered equivalent to $300 + (14 \times 20) = 580$ feet on a level.

Trautwine assumes the average load for all classes of work to be $\frac{1}{2}$ cubic yard, which figure is justified by large experience. Using one figure for all classes of work simplifies the calculations and gives the number of cubic yards carried per day of 10 hours equal to $\frac{600}{3(s + 4)}$. Dividing the cost of a cart per day by the number of cubic yards carried gives the cost of hauling per yard. In computing the cost of a cart per day, Trautwine refers to the practice of having one driver manage four carts, thus making a charge of 25 c. per day for each cart for the driver. 75 c. is allowed for the horse, which is supposed to be the total cost, including that for Sundays and rainy days. 25 c. more is allowed for the cart, harness, repairs, etc., thus making a total cost of \$1.25 per day. Some contractors employ a greater number of drivers and expect each to assist in loading. There is found to be no saving in total cost per yard, while the chances of loafing are perhaps greater. Morris instances five actual cases in which the cost of the cart (reduced to the basis of

\$1 per day for labor) varied from \$1.37 to \$1.48. The items of these costs were not given.

Since the time required for loading loose rock is greater than for earthwork, less loads will be hauled per day. The time allowance for loading, etc., is estimated by Trautwine as 6 minutes instead of 4 as for earth. Considering the great expansion of rock when broken up (see § 97), one cubic yard of solid rock, measured in place, would furnish the equivalent of five loads of earthwork of $\frac{1}{5}$ cubic yard. Therefore, on the basis of five loads per cubic yard, the number of cubic yards handled per day per cart would be $\frac{600}{5(s+6)}$.

$$\text{Cost per yard in cents} = \frac{125 \times 5(s+6)}{600}. \quad (71)$$

(b) **Wagons.** For longer leads (i.e., from $\frac{1}{8}$ to $\frac{3}{8}$ of a mile) wagons drawn by two horses have been found most economical. The wagons have bottoms of loose thick narrow boards and are unloaded very easily and quickly by lifting the individual boards and breaking up the continuity of the bottom, thus depositing the load directly underneath the wagon. The capacity is about one cubic yard. The cost may be estimated on the same principles as that for carts.

(c) **Wheelbarrows.** According to Trautwine, the speed of moving wheelbarrows may be considered the same as for carts, 200 feet per minute; the time spent in loading and dumping is $1\frac{1}{4}$ minutes, and in addition about $\frac{1}{10}$ of the time is wasted in short rests, adjusting the wheeling plants, etc. On the basis of \$1 per day for labor, an allowance of 5 c. for the barrow, and 14 loads per cubic yard, the cost of hauling per cubic yard (computed on the same principles as above) will be

$$\frac{105 \times 14(s+1.25)}{600 \times 0.9} \dots \dots \dots (72)$$

For rockwork the number of loads per cubic yard is estimated as 24, and the time spent in loading, etc., estimated at 1.6 minutes instead of 1.25 minutes, which makes the estimate

$$\text{Cost per cubic yard} = \frac{105 \times 24(s + 1.6)}{600 \times 0.9}. \quad (73)$$

(d) **Scrapers.** * Scrapers, or scoops, are especially useful in canal work, and also for railroad work when a low embankment is to be formed from borrow-pits at the sides, when the distance does not exceed 100 feet, nor the vertical height 15 feet. The slope should not exceed 1.5 to 1. Under these conditions scraper work is cheaper than any other method. Scooping may be done all in one direction, in which case two half-turns are made for each load moved; or it may be done in both directions (from both sides on to a bank, or, in canal work, from the center to each bank), in which case one load is hauled to each half-turn. The capacity of the scoops (the “drag” variety) is $\frac{1}{10}$ cubic yard; the time lost in loading, unloading, and all other ways per load (except in turning) will average $\frac{3}{4}$ minute; the time lost in each half-turn (semi-circle) is $\frac{1}{8}$ minute; the speed of the horses may be estimated as 70 feet of *lead* per minute, the lead being here considered as the *sum* of the vertical and horizontal distances, and the estimate including the time of going and returning. If a represents the sum of the horizontal and vertical distances, the number of cubic yards handled per day of 10 hours by “side-scooping” will be

$$0.1 \left(\frac{600}{\frac{a}{70} + 1\frac{1}{8}} \right), \text{ which equals } \frac{4200}{a + 93\frac{1}{8}}.$$

For “double-scooping” the formula becomes

$$0.1 \left(\frac{600}{\frac{a}{70} + 1} \right), \text{ which equals } \frac{4200}{a + 70}.$$

* Condensed from Journ. Franklin Inst., Oct. 1841, by Morris.

Dividing the cost of a scraper per day (estimated at \$2.75) by the number of yards handled per day gives the average cost per yard.

Except in very loose sandy soil it is best to plough the earth first, which will cost *about* 1 c. per yard. (See § 107.) Drag-scrapers are now made chiefly of steel, and their capacity is more nearly 0.15 cubic yard. Wheeled scrapers, having a capacity of about 0.5 cubic yard, are frequently used with even greater economy and for greater distances, as they are cheaper than carts up to 250 or 300 feet of lead. Both drag- and wheel-scrapers are best operated in gangs of perhaps 10, using extra or "snap" teams to help load, and a few extra men to help in loading and unloading. The average cost of one scraper per day may thus be easily calculated and the average number of cubic yards handled per day computed as above, from which the cost per yard may be estimated.

(e) **Cars and horses.** The items of cost by this method are (a) charge for horses employed, (b) charge for men employed strictly in hauling, (c) charge for shifting rails when necessary, (d) repairs, depreciation, and interest on cost of cars and track. Part of this cost should strictly be classified under items 5 and 6, mentioned in § 106, but it is perhaps more convenient to estimate them as follows.

The traction of a car on rails is so very small and constant that grade resistance constitutes a very large part of the total resistance if the grade is 1% or more. For all ordinary grades it is sufficiently accurate to say that the grade resistance is to the gross weight as the rise is to the distance. If the distance is supposed to be measured along the slope, the proportion is strictly true; i.e., on a 1% grade the grade resistance is 1 lb. per 100 of weight or 20 lbs. per ton. If the resistance on a level at the usual velocity is $\frac{1}{120}$, a grade of 1:120 (0.83%) will exactly double it. If the material is hauled *down* a grade of 1:120, the cars will run by gravity after being started. The work of hauling will then consist practically of hauling the empty cars up the grade. The grade resistance depends only

on the rate of grade and the weight, but the tractive resistance will be *greater per ton of weight* for the unloaded than for the loaded cars. The tractive power of a horse is less on a grade than on a level, not only because the horse raises his own weight in addition to the load, but is anatomically less capable of pulling on a grade than on a level. In general it will be possible to plan the work so that loaded cars need not be hauled *up* a grade, unless an embankment is to be formed from a low borrow-pit, in which case another method would probably be advisable. These computations are chiefly utilized in designing the method of work—the proportion of horses to cars. An example may be quoted from English practice (Hurst), in which the cars had a capacity of $3\frac{1}{2}$ cubic yards, weighing 30 cwt. empty. Two horses took five “*wagons*” $\frac{1}{4}$ of a mile on a level railroad and made 15 journeys per day of 10 hours, i.e., they handled 250 yards per day. In addition to those on the “*straight road*,” another horse was employed to make up the train of loaded wagons. With a short lead the straight-road horses were employed for this purpose. In the above example the number of men required to handle these cars, shift the tracks, etc., is not given, and so the exact cost of the above work cannot be analyzed. It may be noticed that the two horses travelled $22\frac{1}{2}$ miles per day, drawing in one direction a load, including the weight of the cars, of about 57,300 lbs. or 28.65 net tons. Allowing $\frac{1}{120}$ as the necessary tractive force, it would require a pull of 477.5 lbs., or 239 lbs. for each horse. With a velocity of 220 feet per minute this would amount to $1\frac{1}{2}$ horse-power per horse, exerted for only a short time, however, and allowing considerable time for rest and for drawing only the empty cars. The cars generally used in this country have a capacity of $1\frac{1}{2}$ cubic yards and cost about \$65 apiece. Besides the shovellers and dumping-gang, several men and a foreman will be required to keep the track in order and to make the constant shifts that are necessary. Two trains are generally used, one of which is loaded while the other is run to the dump. Some passing-place is necessary, but this is generally

provided by having a switch at the cut and running the trains on each track alternately. This insures a train of cars always at the cut to keep the shovellers employed. The cost of hauling per cubic yard can only be computed when the number of laborers, cars, and horses employed are known, and these will depend on the lead, on the character of the excavation, on the grade, if any, etc., and must be so proportioned that the shovellers need not wait for cars to fill, nor the dumping-gang for material to handle, nor the horses and drivers for cars to haul. Much skill is necessary to keep a large force in smooth running order.

(f) **Cars and locomotives.** 30-lb. rails are the lightest that should be used for this work, and 35- or 40-lb. rails are better. One or two narrow-gauge locomotives (depending on the length of haul), costing about \$2500 each, will be necessary to handle two trains of about 15 cars each, the cars having a capacity of about 2 cubic yards and costing about \$100 each. Some cars can be obtained as low as \$70. A force of about five men and a foreman will be required to shift the tracks. The track-shifters, except the foreman, may be common laborers. The dumping-gang will require about seven men. Even when the material is all taken *down* grade the grades may be too steep for the safe hauling of loaded cars down the grade, or for hauling empty cars up the grade. Under such circumstances temporary trestles are necessary to reduce the grade. When these are used, the uprights and bracing are left in the embankment—only the stringers being removed. This is largely a necessity, but is partially compensated by the fact that the trestle forms a core to the embankment which prevents lateral shifting during settlement. The average speed of the trains may be taken as 10 miles per hour or 5 miles of lead per hour. The time lost in loading and unloading is estimated (Trautwine) as 9 minutes or .15 of an hour. The number of trips per day of 10 hours will equal $\frac{10}{\frac{1}{2}(\text{miles of lead}) + .15}$ or $\frac{50}{(\text{miles of lead}) + .75}$. Of course this quotient *must* be a whole number. Knowing the

number of trains and their capacity, the total number of cubic yards handled is known, which, divided into the total daily cost of the trains, will give the cost of hauling per yard. The daily cost of a train will include

(a) Wages of engineer, who frequently fires his own engine;
(b) Fuel, about $\frac{1}{4}$ to 1 ton of bituminous coal, depending on work done;

(c) Water, a very variable item, frequently costing \$3 to \$5 per day;

(d) Repairs, variable, frequently at rate of 50 to 60% per year;

(e) Interest on cost and depreciation, 16 to 40%.

To these must be added, to obtain the total cost of the haul,

(f) Wages of the gang employed in shifting track.

110. Choice of method of haul dependent on distance.

In light side-hill work in which material need not be moved more than 12 or 15 feet, i.e., moved *laterally* across the road-bed, the earth may be moved most cheaply by mere shovelling. Beyond 12 feet scrapers are more economical. At about 100 feet drag-scrappers and wheelbarrows are equally economical. Between 100 and 200 feet wheelbarrows are generally cheaper than either carts or drag-scrappers, but wheeled scrapers are always cheaper than wheelbarrows. Beyond 500 feet two-wheeled carts become the most economical up to about 1700 feet; then four-wheeled wagons become more economical up to 3500 feet. Beyond this cars on rails, drawn by horses or by locomotives, become cheaper. The economy of cars on rails becomes evident for distances as small as 300 feet provided the volume of the excavation will justify the outlay. Locomotives will always be cheaper than horses and mules providing the work to be done is of sufficient magnitude to justify the purchase of the necessary plant and risk the loss in selling the plant ultimately as second-hand equipment, or keeping the plant on hand and idle for an indefinite period waiting for other work. Horses will not be economical for distances much over a mile. For greater distances locomotives are more economical, but the

question of "limit of profitable haul" (§ 116) must be closely studied, as the circumstances are certainly not common when it is advisable to haul material much over a mile.

111. Item 4. SPREADING. The cost of spreading varies with the method employed in dumping the load. When the earth is tipped over the edge of an embankment there is little if any necessary work. Trautwine allows about $\frac{1}{4}$ c. per cubic yard for keeping the dumping-places clear and in order. This would represent the wages of one man at \$1 per day attending to the unloading of 1200 two-wheeled carts each carrying $\frac{1}{8}$ cubic yard. 1200 carts in 10 hours would mean an average of two per minute, which implies more rapid and efficient work than may be depended on. The allowance is probably too small. When the material is dumped in layers some levelling is required, for which Trautwine allows 50 to 100 cubic yards as a fair day's work, costing from 1 to 2 cents per cubic yard. The cost of spreading will not ordinarily exceed this and is frequently nothing—all depending on the method of unloading. It should be noted that Mr. Morris's examples and computations (Jour. Franklin Inst., Sept. 1841) disregard altogether any special charge for this item.

112. Item 5. KEEPING ROADWAYS IN ORDER. This feature is important as a measure of true economy, whatever the system of transportation, but it is often neglected. A petty saving in such matters will cost many times as much in increased labor in hauling and loss of time. With some methods of haul the cost is best combined with that of other items.

(a) **Wheelbarrows.** Wheelbarrows should generally be run on planks laid on the ground. The adjusting and shifting of these planks is done by the wheelers, and the time for it is allowed for in the 10% allowance for "short rests, adjusting the wheeling plank, etc." The actual cost of the planks must be added, but it would evidently be a very small addition per cubic yard in a large contract. When the wheelbarrows are run on planks placed on "horses" or on trestles the cost is very appreciable; but the method is frequently used with great economy. The

variations in the requirements render any general estimate of such cost impracticable.

(b) **Carts and wagons.** The cost of keeping roadways in order for carts and wagons is sometimes estimated merely as so much per cubic yard, but it is evidently a function of the *lead*. The work consists in draining off puddles, filling up ruts, picking up loose stones that may have fallen off the loads, and in general doing everything that will reduce the traction as much as possible. Temporary inclines, built to avoid excessive grade at some one point, are often measures of true economy. Trautwine suggests $\frac{1}{10}$ c. per cubic yard per 100 feet of lead for earthwork and $\frac{2}{10}$ c. for rockwork, as an estimate for this item when carts are used.

(c) **Cars.** When cars are used a shifting-gang, consisting of a foreman and several men (say five), are constantly employed in shifting the track so that the material may be loaded and unloaded where it is desired. The average cost of this item may be estimated by dividing the total daily cost of this gang by the number of cubic yards handled in one day.

113. Item 6. REPAIRS, WEAR, DEPRECIATION, AND INTEREST ON COST OF PLANT. The amount of this item evidently depends upon the character of the soil—the harder the soil the worse the wear and depreciation. The *interest on cost* depends on the current borrowing value of money. The estimate for this item has already been included in the allowances for horses, carts, ploughs, harness, wheelbarrows, steam-shovels, etc. Trautwine estimates $\frac{1}{4}$ c. per cubic yard for picks and shovels. Depreciation is generally a large percentage of the cost of earth-working tools, the life of all being limited to a few years, and of many tools to a few months.

114. Item 7. SUPERINTENDENCE AND INCIDENTALS. The incidentals include water-carriers, trimming cuts to grade, digging the side ditches, trimming up the sides of borrow-pits to prevent their becoming unsightly, etc. These last operations yield but little earth and cost far more than the price paid per cubic yard. Morris allows 1 c. per cubic yard for this item; Trautwine

allows $1\frac{3}{4}$ to 2 c. for it; while others combine items 6 and 7 and call them 5% of the total cost, which method has the merit of making the cost of items 6 and 7 a function of the character of soil and length of lead.

115. Item 8. CONTRACTOR'S PROFIT. This is usually estimated at from 6 to 15%, according to the sharpness of the competition and the possible uncertainty as to true cost owing to unfavorable circumstances. The contractor's real profit may vary considerably from this. He often pays clerks, boards and lodges the laborers in shanties built for the purpose, or keeps a supply-store, and has various other items both of profit and expense. His profit is largely dependent on skill in so handling the men that all can work effectively without interference or delays in waiting for others. An unusual season of bad weather will often affect the cost very seriously. It is a common occurrence to find that two contractors may be working on the same kind of material and under precisely similar conditions and at the same price, and yet one may be making money and the other losing it—all on account of difference of management.

116. Limit of profitable haul. As intimated in §§ 103 and 110, there is with every method of haul a limit of distance beyond which the expense for excessive hauling will exceed the loss resulting from borrowing and wasting. This distance is somewhat dependent on local conditions, thus requiring an independent solution for each particular case, but the general principles involved will be about as follows: Assume that it has been determined, as in Fig. 62, that the cut and fill will exactly balance between two points, as between e and x , assuming that, as indicated in § 101 (9), a trestle has been introduced between s and t , thus altering the mass curve to *Estxn* . . . Since there is a balance between A' and C' , the material for the fill between C' and e' must be obtained either by "borrowing" in the immediate neighborhood or by transportation from the excavation between z' and n' . If cut and fill have been approximately balanced in the selection of grade line, as is ordinarily done, borrowing material for the fill $C'e'$ implies a wastage of material

at the cut $z'n'$. To compare the two methods, we may place against the plan of borrowing and wasting, (a) cost, if any, of extra right of way that may be needed from which to obtain earth for the fill $C'e'$; (b) cost of loosening, loading, hauling a distance equal to that between the centers of gravity of the borrow-pit and of the fill, and the other expenses incidental to borrowing M cubic yards for the fill $C'e'$; (c) cost of loosening, loading, hauling a distance equal to that between the centers of gravity of the cut $z'n'$ and of the spoil-bank, and the other expenses incidental to wasting M cubic yards at the cut $z'n'$; (d) cost, if any, of land needed for the spoil-bank. The cost of the other plan will be the cost of loosening, loading, hauling (the hauling being represented by the trapezoidal figure $Cexn$), and the other expenses incidental to making the fill $C'e'$ with the material from the cut $z'n'$, the amount of material being M cubic yards, which is represented in the figure by the vertical ordinate from e to the line Cn . The difference between these costs will be the cost, if any, of land for borrow-pit and spoil-bank *plus* the cost of loosening, loading, etc. (except hauling and roadways) of M cubic yards, *minus* the difference in cost of the excessive haul from Ce to xn and the comparatively short hauls from borrow-pit and to spoil-bank.

As an illustration, taking some of the estimates previously given for operating with average material, the cost of all items, except hauling and roadways, would be about as follows: loosening, with plough, 1.2 c., loading 5.0 c., spreading 1.5 c., wear, depreciation, etc., .25 c., superintendence, etc., 1.5 c.; total 8.95 c. Suppose that the haul for both borrowing and wasting averages 100 feet or 1 station. Then the cost of haul per yard, using carts, would be (§ 109, a) $[125 \times 3(1 + 4)] \div 600 = 3.125$ c. The cost of roadways would be about 0.1 c. per yard, making a total of 3.225 c. per cubic yard. Assume $M = 10000$ cubic yards and the area $Cexn = 180000$ yards-stations or the equivalent of 10000 yards hauled 1800 feet. This haul would cost $[125 \times 3(18 + 4)] \div 600 = 13.75$ c. per cubic yard. The cost of roadways will be $18 \times .1$ or 1.8 c.,

making a total of 15.55 c. for hauling and roadways. The difference of cost of hauling and roadways will be $15.55 - (2 \times 3.225) = 9.10$ c. per yard or \$910 for the 10000 yards. Offsetting this is the cost of loosening, etc., 10000 yards, at 8.95 c., costing \$895. These figures may be better compared as follows:

LONG HAUL.	{	Loosening, etc., 10000 yards, @ 8.95 c.	\$ 895.
		Hauling, " 10000 " @ 15.55 c.	1555.
			<hr/> \$2450. <hr/>
BORROWING AND WASTING.	{	Loosening, etc., 10000 yards (borrowed), @ 8.95 c.	\$895.
		" " 10000 " (wasted), @ 8.95 c.	895.
		Hauling, etc., 10000 " (borrowed), @ 3.225 c.	322.50
		" " 10000 " (wasted), @ 3.225 c.	322.50
			<hr/> \$2435.00 <hr/>

These costs are practically balanced, but no allowance has been made for right of way. If any considerable amount had to be paid for that, it would decide this particular case in favor of the long haul. This shows that *under these conditions* 1800 feet is *about* the limit of profitable haul, the land costing nothing extra.

BLASTING.

117. Explosives. The effect of blasting is due to the extremely rapid expansion of a gas which is developed by the decomposition of a very small amount of solid matter. Blasting compounds may be divided into two general classes, (a) slow-burning and (b) detonating. Gunpowder is a type of the slow-burning compounds. These are generally ignited by heat; the ignition proceeds from grain to grain; the heat and pressure produced are comparatively low. Nitro-glycerine is a type of the detonating compounds. They are exploded by a shock which *instantaneously* explodes the whole mass. The heat and pressure developed are far in excess of that produced by the explosion of powder. Nitro-glycerine is so easily exploded that it is very dangerous to handle. It was discovered that if the nitro-glycerine was absorbed by a spongy material like infu-

sorial earth, it was much less liable to explode, while its power when actually exploded was practically equal to that of the amount of pure nitro-glycerine contained in the dynamite, which is the name given to the mixture of nitro-glycerine and infusorial earth. Nitro-glycerine is expensive; many other explosive chemical compounds which properly belong to the slow-burning class are comparatively cheap. It has been conclusively demonstrated that a mixture of nitro-glycerine and some of the cheaper chemicals has a greater explosive force than the sum of the strengths of the component parts when exploded separately. Whatever the reason, the fact seems established. The reason is possibly that the explosion of the nitro-glycerine is sufficiently powerful to produce a *detonation* of the other chemicals, which is impossible to produce by ordinary means, and that this explosion caused by detonation is more powerful than an ordinary explosion. The majority of the explosive compounds and "powders" on the market are of this character—a mixture of 20 to 60 per cent. of nitro-glycerine with variable proportions of one or more of a great variety of explosive chemicals.

The choice of the explosive depends on the character of the rock. A hard brittle rock is most effectively blasted by a detonating compound. The rapidity with which the full force of the explosive is developed has a shattering effect on a brittle substance. On the contrary, some of the softer tougher rocks and indurated clays are but little affected by dynamite. The result is but little more than an enlargement of the blast-hole. Quarrying must generally be done with blasting-powder, as the quicker explosives are too shattering. Although the results obtained by various experimenters are very variable, it may be said that pure nitro-glycerine is eight times as powerful as black powder, dynamite (75% nitro-glycerine) six times, and gun-cotton four to six times as powerful. For open work where time is not particularly valuable, black powder is by far the cheapest, but in tunnel-headings, whose progress determines the progress of the whole work, dynamite is so much more effective and so expedites the work that its use becomes economical.

118. Drilling. Although many very complicated forms of drill-bars have been devised, the best form (with slight modifications to suit circumstances) is as shown in Fig. 64, (a) and (b).

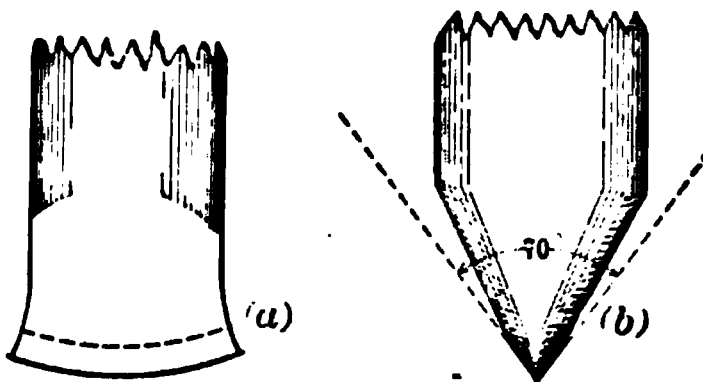


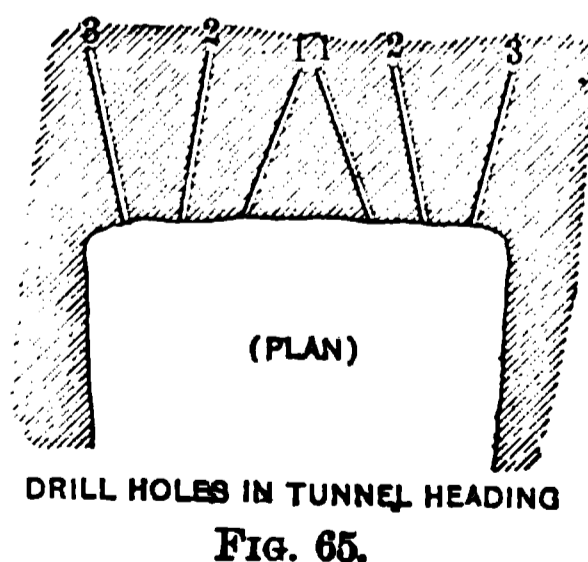
FIG. 64.

The width should flare at the bottom (a) about 15 to 30%. For hard rock the curve of the edge should be somewhat flatter and for soft rock somewhat more curved than shown, Fig. 64, (a). Sometimes the angle of the two faces is varied from that given, Fig. 64, (b), and occasionally the edge is purposely blunted so as to give a crushing rather than a cutting effect. The drills will require sharpening for each 6 to 18 inches depth of hole, and will require a new edge to be worked every 2 to 4 days. For drilling vertical holes the *churn-drill* is the most economical. The drill-bar is of iron, about 6 to 8 feet long, $1\frac{1}{4}$ " in diameter, weighs about 25 to 30 lbs., and is shod with a piece of steel welded on. The bar is lifted a few inches between each blow, turned partially around, and allowed to fall, the impact doing the work. From 5 to 15 feet of holes, depending on the character of the rock, is a fair day's work—10 hours. In very soft rocks even more than this may be done. This method is inapplicable for inclined holes or even for vertical holes in confined places, such as tunnel-headings. For such places the only practical *hand* method is to use hammers. This may be done by light drills and light hammers (one-man work), or by heavier drills held by one man and struck by one or two men with heavy hammers. The conclusion of an exhaustive investigation as to the relative economy of light or heavy hammers is that the light-hammer method is more economical for the softer rocks, the heavy-hammer method is more economical for the harder

rocks, but that the light-hammer method is always more expeditious and hence to be preferred when time is important.

The subject of machine rock-drills is too vast to be treated here. The method is only practicable when the amount of work to be done is large, and especially when time is valuable. The machines are generally operated by compressed air for tunnel-work, thus doing the additional service of supplying fresh air to the tunnel-headings where it is most needed. The cost per foot of hole drilled is quite variable, but is usually somewhat less than that of hand-drilling—sometimes but a small fraction of it.

119. Position and direction of drill-holes. As the cost of drilling holes is the largest single item in the total cost of blasting, it is necessary that skill and judgment should be used in so locating the holes that the blasts will be most effective. The greatest effect of a blast will evidently be in the direction of the “line of least resistance.” In a strictly homogeneous material this will be the shortest line from the center of the explosive to the surface. The variations in homogeneity on account of laminations and seams require that each case shall be judged according to experience. In open-pit blasting it is generally easy to obtain two and sometimes three exposed faces to the rock, making it a simple matter to drill holes so that a blast will do effective work. When a solid face of rock must be broken into, as in a tunnel-heading, the work is necessarily ineffectual and expensive. A conical or wedge-shaped mass will first be blown out by simultaneous blasts in the holes marked 1, Fig. 65; blasts in the holes marked 2 and 3 will then complete the cross-section of the heading. A great saving in cost may often be secured by skilfully taking advantage of seams, breaks, and irregularities. When the work is economically done there is but little noise or throwing of rock,



a covering of old timbers and branches of trees generally sufficing to confine the smaller pieces which would otherwise fly up.

120. Amount of explosive. The amount of explosive required varies as the cube of the line of least resistance. The best results are obtained when the line of least resistance is $\frac{2}{3}$ of the depth of the hole; also when the powder fills about $\frac{1}{8}$ of the hole. For average rock the amount of powder required is as follows:

Line of least resistance.....	2 ft.	4 ft.	6 ft.	8 ft.
Weight of powder.....	$\frac{1}{4}$ lb.	2 lbs.	$6\frac{3}{4}$ lbs.	16 lbs.

Strict compliance with all of the above conditions would require that the diameter of the hole should vary for every case. While this is impracticable, there should evidently be some variation in the size of the hole, depending on the work to be done. For example, a 1" hole, drilled 2' 8" deep, with its line of least resistance 2', and loaded with $\frac{1}{4}$ lb. of powder, would be filled to a depth of $9\frac{1}{2}$ ", which is nearly $\frac{1}{8}$ of the depth. A 3" hole, drilled 8' deep, with its line of least resistance 6', and loaded with $6\frac{3}{4}$ lbs. of powder, would be filled to a depth of over 28", which is also nearly $\frac{1}{8}$ of the depth. One pound of blasting-powder will occupy about 28 cubic inches. Quarrying necessitates the use of numerous and sometimes repeated light charges of powder, as a heavy blast or a powerful explosive like dynamite is apt to shatter the rock. This requires more powder to the cubic yard than blasting for mere excavation, which may usually be done by the use of $\frac{1}{4}$ to $\frac{1}{8}$ lb. of powder per cubic yard of easy open blasting. On account of the great resistance offered by rock when blasted in headings in tunnels, the powder used per cubic yard will run up to 2, 4, and even 6 lbs. per cubic yard. As before stated, nitro-glycerine is about eight times (and dynamite about six times) as powerful as the same *weight* of powder.

121. Tamping. Blasting-powder and the slow-burning explosives require thorough tamping. Clay is probably the best,

but sand and fine powdered rock are also used. Wooden plugs, inverted expansive cones, etc., are periodically reinvented by enthusiastic inventors, only to be discarded for the simpler methods. Owing to the extreme rapidity of the development of the force of a nitro-glycerine or dynamite explosion, tamping is not so essential with these explosives, although it unquestionably adds to their effectiveness. Blasting under water has been effectively accomplished by merely pouring nitro-glycerine into the drilled holes through a tube and then exploding the charge without any tamping except that furnished by the superincumbent water. It has been found that air-spaces about a charge make a material reduction in the effectiveness of the explosion. It is therefore necessary to carefully ram the explosive into a solid mass. Of course the liquid nitro-glycerine needs no ramming, but dynamite should be rammed with a *wooden* rammer. Iron should be carefully avoided in ramming gunpowder. A copper bar is generally used.

122. Exploding the charge. Black powder is generally exploded by means of a fuse which is essentially a cord in which there is a thin vein of gunpowder, the cord being protected by tar, extra linings of hemp, cotton, or even gutta-percha. The fuse is inserted into the middle of the charge, and the tamping carefully packed around it so that it will not be injured. To produce the detonation required to explode nitro-glycerine and dynamite, there must be an initial explosion of some easily ignited explosive. This is generally accomplished by means of caps containing fulminating-powder which are exploded by electricity. The electricity (in one class of caps) heats a very fine platinum wire to redness, thereby igniting the sensitive powder, or (in another class) a spark is caused to jump through the powder between the ends of two wires suitably separated. Dynamite can also be exploded by using a small cartridge of gunpowder which is itself exploded by an ordinary fuse.

123. Cost. Trautwine estimates the cost of blasting (for mere excavation) as averaging 45 cents per cubic yard, falling as low as 30 cents for easy but *brittle* rock, and running up to

60 cents and even \$1 when the cutting is shallow, the rock especially tough, and the strata unfavorably placed. Soft tough rock frequently requires more powder than harder brittle rock.

124. Classification of excavated material. The classification of excavated material is a fruitful source of dispute between contractors and railroad companies, owing mainly to the fact that the variation between the softest earth and the hardest rock is so gradual that it is very difficult to describe distinctions between different classifications which are unmistakable and indisputable. The classification frequently used is (*a*) earth, (*b*) loose rock, and (*c*) solid rock. As blasting is frequently used to loosen "loose rock" and even "earth" (if it is frozen), the fact that blasting is employed cannot be used as a criterion, especially as this would (if allowed) lead to unnecessary blasting for the sake of classifying material as rock.

Earth. This includes clay, sand, gravel, loam, decomposed rock and slate, boulders or loose stones not greater than 1 cubic foot (3 cubic feet, P. R. R.), and sometimes even "hard-pan." In general it will signify material which *can* be loosened by a plough with two horses, or with which one picker can keep one shoveller busy.

Loose rock. This includes boulders and loose stones of more than one cubic foot and less than one cubic yard; stratified rock, not more than six inches thick, separated by a stratum of clay; also all material (not classified as earth) which may be loosened by pick or bar and which "*can* be quarried without blasting, although blasting may occasionally be resorted to."

Solid rock includes all rock found in masses of over one cubic yard which cannot be removed except by blasting.

It is generally specified that the engineer of the railroad company shall be the judge of the classification of the material, but frequently an appeal is taken from his decisions to the courts.

125. Specifications for earthwork. The following specifications, issued by the Norfolk and Western R. R., represent the average requirements. It should be remembered that very strict

specifications invariably increase the cost of the work, and frequently add to the cost more than is gained by improved quality of work.

1. The grading will be estimated and paid for by the cubic yard, and will include clearing and grubbing, and all open excavations, channels, and embankments required for the formation of the roadbed, and for turnouts and sidings; cutting all ditches or drains about or contiguous to the road; digging the foundation-pits of all culverts, bridges, or walls; reconstructing turnpikes or common roads in cases where they are destroyed or interfered with; changing the course or channel of streams; and all other excavations or embankments connected with or incident to the construction of said Railroad.

2. All grading, except where otherwise specified, whether for cuts or fills, will be measured in the excavations and will be classified under the following heads, viz.: Solid Rock, Loose Rock, Hard-pan, and Earth.

SOLID ROCK shall include all rock occurring in masses which, in the judgment of the said Engineer Maintenance of Way, may be best removed by blasting.

LOOSE ROCK shall include all kinds of shale, soapstone, and other rock which, in the judgment of the said Engineer Maintenance of Way, can be removed by pick and bar, and is soft and loose enough to be removed without blasting, although blasting may be occasionally resorted to; also, detached stone of less than one (1) cubic yard and more than one (1) cubic foot.

HARD-PAN shall consist of tough indurated clay or cemented gravel, which requires blasting or other equally expensive means for its removal, or which cannot be ploughed with less than four horses and a railroad plough, or which requires two pickers to a shoveller, the said Engineer Maintenance of Way to be the judge of these conditions.

EARTH shall include all material of an earthy nature, of whatever name or character, not unquestionably loose rock or hard-pan as above defined.

POWDER. The use of powder in cuts will not be considered

as a reason for any other classification than earth, unless the material in the cut is clearly other than earth under the above specifications.

3. Earth, gravel, and other materials taken from the excavations, except when otherwise directed by the said Engineer Maintenance of Way or his assistant, shall be deposited in the adjacent embankment; the cost of removing and depositing which, when the distance necessary to be hauled is not more than sixteen hundred (1600) feet, shall be included in the price paid for the excavation.

4. EXTRA HAUL will be estimated and paid for as follows: whenever material from excavations is necessarily hauled a greater distance than sixteen hundred (1600) feet, there shall be paid in addition to the price of excavation the price of extra haul per 100 feet, or part thereof, after the first 1600 feet; the necessary haul to be determined in each case by the said Engineer Maintenance of Way or his assistant, from the profile and cross-sections, and the estimates to be in accordance therewith.

5. All embankments shall be made in layers of such thickness and carried on in such manner as the said Engineer Maintenance of Way or his assistant may prescribe, the stone and heavy materials being placed in slopes and top. And in completing the fills to the proper grade such additional heights and fulness of slope shall be given them, to provide for their settlement, as the said Engineer Maintenance of Way, or his assistant, may direct. Embankments about masonry shall be built at such times and in such manner and of such materials as the said Engineer Maintenance of Way or his assistant may direct.

6. In procuring materials for embankments from without the line of the road, and in wasting materials from cuttings, the place and manner of doing it shall in each case be indicated by the Engineer Maintenance of Way or his assistant; and care must be taken to injure or disfigure the land as little as possible. Borrow-pits and spoil-banks must be left by the Contractor in regular and sightly shape.

7. The lands of the said Railroad Company shall be cleared

to the extent required by the said Engineer Maintenance of Way, or his assistant, of all trees, brushes, logs, and other perishable materials, which shall be destroyed by burning or deposited in heaps as the said Engineer Maintenance of Way, or his assistant, may direct. Large trees must be cut not more than two and one-half ($2\frac{1}{2}$) feet from the ground, and under embankments less than four (4) feet high they shall be cut close to the ground. All small trees and bushes shall be cut close to the ground.

8. Clearing shall be estimated and paid for by the acre or fraction of an acre.

9. All stumps, roots, logs, and other obstructions shall be grubbed out, and removed from all places where embankments occur less than two (2) feet in height; also, from all places where excavations occur and from such other places as the said Engineer Maintenance of Way or his assistant may direct.

10. Grubbing shall be estimated and paid for by the acre or fraction of an acre.

11. Contractors, when directed by the said Engineer Maintenance of Way or his assistant in charge of the work, will deposit on the side of the road, or at such convenient points as may be designated, any stone, rock, or other materials that they may excavate; and all materials excavated and deposited as above, together with all timber removed from the line of the road, will be considered the property of the Railroad Company, and the Contractors upon the respective sections will be responsible for its safe-keeping until removed by said Railroad Company, or until their work is finished.

12. Contractors will be accountable for the maintenance of safe and convenient places wherever public or private roads are in any way interfered with by them during the progress of the work. They will also be responsible for fences thrown down, and for gates and bars left open, and for all damages occasioned thereby.

13. Temporary bridges and trestles, erected to facilitate the progress of the work, in case of delays at masonry structures

from any cause, or for other reasons, will be at the expense of the Contractor.

14. The line of road or the gradients may be changed in any manner, and at any time, if the said Engineer Maintenance of Way or his assistant shall consider such a change necessary or expedient; but no claim for an increase in prices of excavation or embankment on the part of the Contractor will be allowed or considered unless made in writing before the work on that part of the section where the alteration has been made shall have been commenced. The said Engineer Maintenance of Way or his assistant may also, on the conditions last recited, increase or diminish the length of any section for the purpose of more nearly equalizing or balancing the excavations and embankments, or for any other reason.

15. The roadbed will be graded as directed by the said Engineer Maintenance of Way or his assistant, and in conformity with such breadths, depths, and slopes of cutting and filling as he may prescribe from time to time, and no part of the work will be finally accepted until it is properly completed and dressed off at the required grade.

CHAPTER IV.

TRESTLES.

126. Extent of use. Trestles constitute from 1 to 3% of the length of the average railroad. It was estimated in 1889 that there was then about 2400 miles of single-track railway trestle in the United States, divided among 150,000 structures and estimated to cost about \$75,000,000. The annual charge for maintenance, estimated at $\frac{1}{8}$ of the cost, therefore amounted to about \$9,500,000 and necessitated the annual use of perhaps 300,000,000 ft. B.M. of timber. The corresponding figures at the present time must be somewhat in excess of this. The magnitude of this use, which is causing the rapid disappearance of forests, has resulted in endeavors to limit the use of timber for this purpose. Trestles may be considered as justifiable under the following conditions:

a. Permanent trestles.

1. Those of *extreme* height—then called viaducts and frequently constructed of iron or steel, as the Kinzua viaduct, 302 ft. high.

2. Those across waterways—*e.g.*, that across Lake Pontchartrain, near New Orleans, 22 miles long.

3. Those across swamps of soft deep mud, or across a river-bottom, liable to occasional overflow.

b. Temporary trestles.

1. To open the road for traffic as quickly as possible—often a reason of great financial importance.

2. To quickly replace a more elaborate structure, destroyed

by accident, on a road already in operation, so that the interruption to traffic shall be a minimum.

3. To form an earth embankment with earth brought from a distant point by the train-load, when such a measure would cost less than to borrow earth in the immediate neighborhood.

4. To bridge an opening temporarily and thus allow time to learn the regimen of a stream in order to better proportion the size of the waterway and also to facilitate bringing *suitable* stone for masonry from a distance. In a new country there is always the double danger of either building a culvert too small, requiring expensive reconstruction, perhaps after a disastrous washout, or else wasting money by constructing the culvert unnecessarily large. Much masonry has been built of a very poor quality of stone because it could be conveniently obtained and because good stone was unobtainable except at a prohibitive cost for transportation. Opening the road for traffic by the use of temporary trestles obviates both of these difficulties.

127. Trestles vs. embankments. Low embankments are very much cheaper than low trestles both in first cost and maintenance. Very high embankments are very expensive to construct, but cost comparatively little to maintain. A trestle of equal height may cost much less to construct, but will be expensive to maintain—perhaps $\frac{1}{3}$ of its cost per year. To determine the height beyond which it will be cheaper to maintain a trestle rather than build an embankment, it will be necessary to allow for the cost of maintenance. The height will also depend on the relative cost of timber, labor, and earthwork. At the present average values, it will be found that for less heights than 25 feet the *first cost* of an embankment will *generally* be less than that of a trestle; this implies that a permanent trestle should never be constructed with a height less than 25 feet except for the reasons given in § 126. The height at which a permanent trestle is certainly cheaper than earthwork is more uncertain. A high grade line joining two hills will invariably imply at least a culvert if an embankment is used. If the culvert is built of masonry, the cost of the embankment will be

so increased that the height at which a trestle becomes economical will be materially reduced. The cost of an embankment increases much more rapidly than the height—with very high embankments more nearly as the square of the height—while the cost of trestles does not increase as rapidly as the height. Although local circumstances may modify the application of any set rules, it is probably seldom that it will be cheaper to build an embankment 40 or 50 feet high than to permanently maintain a wooden trestle of that height. A steel viaduct would probably be the best solution of such a case. These are frequently used for permanent structures, especially when very high. The cost of maintenance is much less than that of wood, which makes the use of iron or steel preferable for permanent trestles unless wood is abnormally cheap. Neither the cost nor the construction of iron or steel trestles will be considered in this chapter.

128. Two principal types. There are two principal types of wooden trestles—pile trestles and framed trestles. The great objection to pile trestles is the rapid rotting of the portion of the pile which is underground, and the difficulty of renewal. The maximum height of pile trestles is about 30 feet, and even this height is seldom reached. Framed trestles have been constructed to a height of considerably over 100 feet. They are frequently built in such a manner that any injured piece may be readily taken out and renewed without interfering with traffic. Trestles consist of two parts—the supports called “bents,” and the stringers and floor system. As the stringers and floor system are the same for both pile and framed trestles, the “bents” are all that need be considered separately.

PILE TRESTLES.

129. Pile bents. A pile bent consists generally of four piles driven into the ground deep enough to afford not only sufficient vertical resistance but also lateral resistance. On top of these piles is placed a horizontal “cap.” The caps are fastened to the tops of the piles by methods illustrated in Fig. 66. The

method of fastening shown in each case should not be considered as applicable only to the particular type of pile bent used to illustrate it. Fig. 66 (*a* and *d*) illustrates a mortise-joint with a hard-

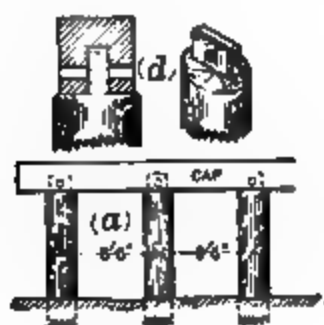


FIG. 66.

wood pin about $1\frac{1}{4}$ " in diameter. The hole for the pin should be bored separately through the cap and the mortise, and the hole through the cap should be at a slightly higher level than that through the mortise, so that the cap will be drawn down tight when the pin is driven. Occasionally an iron dowel (an iron pin about $1\frac{1}{2}$ " in diameter and about 6" long) is inserted partly in the cap and partly in the pile. The use of drift-bolts, shown in Fig. 66 (*b*), is cheaper in first cost, but renders repairs and renewals very troublesome and expensive. "Split caps," shown in Fig. 66 (*c*), are formed by bolting two half-size strips on each side of a tenon on top of the pile. Repairs are very easily and cheaply made without interference with the traffic and without injuring other pieces of the bent. The smaller pieces are more easily obtainable in a sound condition; the decay of one does not affect the other, and the first cost is but little if any greater than the method of using a single piece. For further discussion, see § 136.

For very light traffic and for a height of about 5 feet three vertical piles will suffice, as shown in Fig. 66 (*a*). Up to a height of 8 or 10 feet four piles may be used without sway-bracing, as in Fig. 66 (*b*), if the piles have a good bearing. For heights greater than 10 feet sway-bracing is generally necessary. The outside piles are frequently driven with a batter varying from 1:12 to 1:4.

Piles are made, if possible, from timber obtained in the vicinity of the work. Durability is the great requisite rather than strength, for almost any timber is strong enough (except as noted below) and will be suitable if it will resist rapid decay. The following list is quoted as being in the order of preference on account of durability:

1. Red cedar	5. White pine	9. White oak	12. Black oak
2. Red cypress	6. Redwood	10. Post-oak	13. Hemlock
3. Pitch-pine	7. Elm	11. Red oak	14. Tamarac
4. Yellow pine	8. Spruce		

Red-cedar piles are said to have an average life of 27 years with a possible maximum of 50 years, but the timber is rather weak, and if exposed in a river to flowing ice or driftwood is apt to be injured. Under these circumstances oak is preferable, although its life may be only 13 to 18 years.

130. Methods of driving piles. The following are the principal methods of driving piles:

a. A hammer weighing 2000 to 3000 lbs. or more, sliding in guides, is drawn up by horse-power or a portable engine, and allowed to fall *freely*.

b. The same as above except that the hammer does not fall freely, but drags the rope and revolving drum as it falls and is thus quite materially retarded. The mechanism is a little more simple, but is less effective, and is sometimes made deliberately deceptive by a contractor by retarding the blow, in order to apparently indicate the requisite resistance on the part of the pile.

The above methods have the advantage that the mechanism is cheap and can be transported into a new country with comparative ease, but the work done is somewhat ineffective and costly compared with some of the more elaborate methods given below.

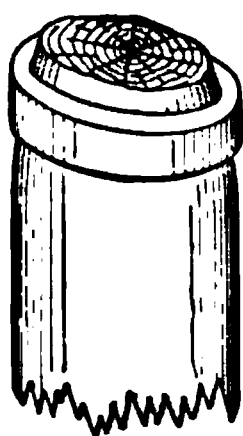
c. Gunpowder pile-drivers, which automatically explode a cartridge every time the hammer falls. The explosion not only forces the pile down, but throws up the hammer for the next blow. For a given height of fall the effect is therefore doubled. It has been shown by experience, however, that when it is at-

tempted to use such a pile-driver rapidly the mechanism becomes so heated that the cartridges explode prematurely, and the method has therefore been abandoned.

d. Steam pile-drivers, in which the hammer is operated directly by steam. The hammer falls freely a height of about 40 inches and is raised again by steam. The effectiveness is largely due to the rapidity of the blows, which does not allow time between the blows for the ground to settle around the pile and increase the resistance, which does happen when the blows are infrequent. "The hammer-cylinder weighs 5500 lbs., and with 60 to 75 lbs. of steam gives 75 to 80 blows per minute. With 41 blows a large unpointed pile was driven 35 feet into a hard clay bottom in half a minute." Such a driver would cost about \$800.

The above four methods are those usual for dry earth. In very soft wet or sandy soils, where an unlimited supply of water is available, the *water-jet* is sometimes employed. A pipe is fastened along the side of the pile and extends to the pile-point. If water is forced through the pipe, it loosens the sand around the point and, rising along the sides, decreases the side resistance so that the pile sinks by its own weight, aided perhaps by extra weights loaded on. This loading may be accomplished by connecting the top of the pile and the pile-driver by a block and tackle so that a portion of the weight of the pile-driver is continually thrown on the pile.

Excessive driving frequently fractures the pile below the surface and thereby greatly weakens its bearing power. To



prevent excessive "brooming" of the top of the pile, owing to the action of the hammer, the top should be protected by an iron ring fitted to the top of the pile. The "brooming" not only renders the driving ineffective and hence uneconomical, but vitiates the value of any test of the bearing power of the pile by noting the sinking due to a given weight falling a given distance. If the pile is so soft that brooming is unavoidable, the top should be adzed off

FIG. 67.

frequently, and especially should it be done just before the final blows which are to test its bearing-power.

In a new country judgment and experience will be required to decide intelligently whether to employ a simple drop-hammer machine, operated by horse-power and easily transported but uneconomical in operation, or a more complicated machine working cheaply and effectively after being transported at greater expense.

131. Pile-driving formulæ. If R = the resistance of a pile, and s the set of the pile during the last blow, w the weight of the pile-hammer, and h the fall during the last blow, then we may state the approximate relation that $Rs = wh$, or $R = \frac{wh}{s}$.

This is the basic principle of all rational formulæ, but the maximum weight which a pile will sustain after it has been driven some time is by no means equal to the resistance of the pile during the last blow. There are also many other modifying elements which have been variously allowed for in the many proposed formulæ. The formulæ range from the extreme of empirical simplicity to very complicated attempts to allow properly for all modifying causes. As the simplest rule, specifications sometimes require that the piles shall be driven until the pile will not sink more than 5 inches under five consecutive blows of a 2000 lb., hammer falling 25 feet. The "*Engineering News* formula"* gives the safe load as

$\frac{2wh}{s + 1}$, in which w = weight of hammer, h = fall in feet, s = set of pile in inches under the last blow. This formula is derived from the above basic formula by calling the safe load $\frac{1}{4}$ of the final resistance, and by adding (arbitrarily) 1 to the final set (s) as a compensation for the extra resistance caused by the settling of earth around the pile between each blow. This formula is used only for ordinary hammer-driving. When the piles are driven by a steam pile-driver the formula becomes

* *Engineering News*, Nov. 17, 1892.

safe load $= \frac{2wh}{s+0.1}$. For the "gunpowder pile-driver," since the explosion of the cartridge drives the pile in with the same force with which it throws the hammer upward, the effect is *twice* that of the fall of the hammer, and the formula becomes safe load $= \frac{4wh}{s+0.1}$. In these last two formulæ the constant

in the denominator is changed from $s+1$ to $s+0.1$. The constant (1.0 or 0.1) is supposed to allow, as before stated, for the effect of the extra resistance caused by the earth settling around the pile between each blow. The more rapid the blows the less the opportunity to settle and the less the proper value of the constant.

The above formulæ have been given on account of their simplicity and their practical agreement with experience. Many other formulæ have been proposed, the majority of which are more complicated and attempt to take into account the weight of the pile, resistance of the guides, etc. While these elements, as well as many others, have their influence, their effect is so overshadowed by the indeterminable effect of other elements—as, for example, the effect of the settlement of earth around the pile between blows—that it is useless to attempt to employ anything but a purely empirical formula.

132. Pile-points and pile-shoes. Piles are generally sharpened to a blunt point. If the pile is liable to strike boulders, sunken logs, or other obstructions which are liable to turn the point, it



FIG. 68.

is necessary to protect the point by some form of shoe. Several forms in cast iron have been used, also a wrought-iron shoe, having four "straps" radiating from the apex, the straps being nailed on to the pile, as shown in Fig. 68 (b). The cast-iron form shown in Fig. 68 (a) has a base cast around a drift-bolt. The recess on the top of the base receives the bottom of the pile and prevents a tendency to split the bottom of the pile or to force the shoe off laterally.

133. Details of design. No theoretical calculations of the strength of pile bents need be attempted on account of the extreme complication of the theoretical strains, the uncertainty as to the real strength of the timber used, the variability of that strength with time, and the insignificance of the economy that would be possible even if exact sizes could be computed. The piles are generally required to be not less than 10" or 12" in diameter at the large end. The P. R. R. requires that they shall be "not less than 14 and 7 inches in diameter at butt and small end respectively, exclusive of bark, which must be removed." The removal of the bark is generally required in good work. Soft *durable* woods, such as are mentioned in § 129, are best for the piles, but the caps are generally made of oak or yellow pine. The caps are generally 14 feet long (for single track) with a cross-section 12" \times 12" or 12" \times 14". "Split caps" would consist of two pieces 6" \times 12". The sway-braces, never used for less heights than 6', are made of 3" \times 12" timber, and are spiked on with $\frac{3}{8}$ " spikes 8' long. The floor system will be the same as that described later for framed trestles.

134. Cost of pile trestles. The cost, per linear foot, of piling depends on the method of driving, the scarcity of suitable timber, the price of labor, the length of the piles, and the amount of shifting of the pile-driver required. The cost of soft-wood piles varies from 8 to 15 c. per lineal foot, and the cost of oak piles varies from 10 to 30 c. per foot according to the length, the longer piles costing more per foot. The cost of driving will average about \$2.50 per pile, or 7.5 to 10 c. per lineal foot. Since the cost of shifting the pile-driver is quite an item in the total cost, the cost of driving a long pile would be *less* per foot than for a short pile, but on the other hand the cost of the pile is *greater* per foot, which tends to make the total cost per foot constant. Specifications generally say that the piling will be paid for per lineal foot of piling *left in the work*. The wastage of the tops of piles sawed off is always something, and is frequently very large. Sometimes a small amount per foot of piling sawed off is allowed the contractor as compensation for

his loss. This reduces the contractor's risk and possibly reduces his bid by an equal or greater amount than the extra amount actually paid him.

FRAMED TRETTLES.

135. Typical Design. A typical design for a framed trestle bent is given in Fig. 69. This represents, with slight variations of detail, the plan according to which a large part of the framed

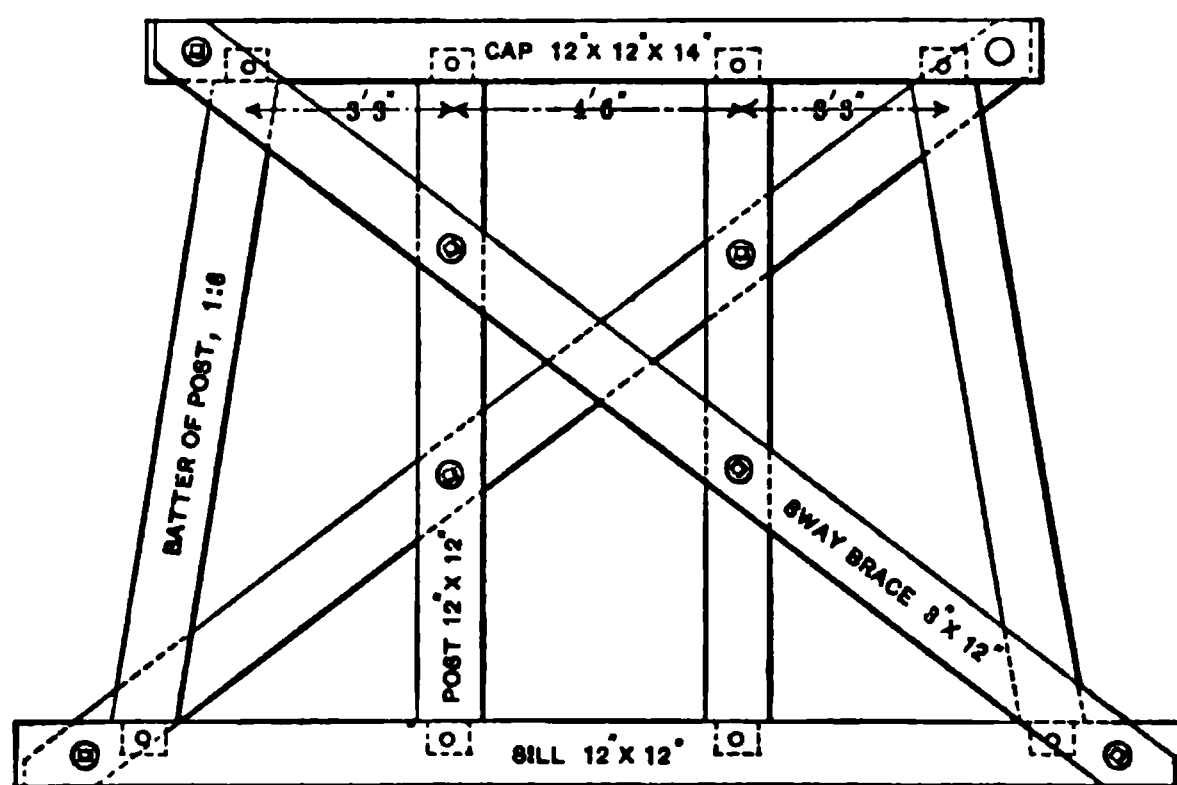


FIG. 69.

trestle bents of the country have been built—i.e., of those less than 20 or 30 feet in height, not requiring multiple-story construction.

136. Joints. (a) The mortise-and-tenon joint is illustrated in Fig. 69 and also in Fig. 66 (a). The tenon should be about 3" thick, 8" wide, and 5½" long. The mortise should be cut a little deeper than the tenon. "Drip-holes" from the mortise

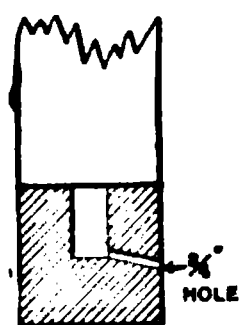


FIG. 70.

to the outside will assist in draining off water that may accumulate in the joint and thus prevent the rapid decay that would otherwise ensue. These joints are very troublesome if a single post decays and requires renewal. It is generally required that the mortise and tenon should be thoroughly daubed with paint before putting them together. This will tend to

make the joint water-tight and prevent decay from the accumulation and retention of water in the joint.

(b) **The plaster joint.** This joint is made by bolting and spiking a 3" \times 12" plank on both sides of the joint. The cap and sill should be notched to receive the posts. Repairs are greatly facilitated by the use of these joints. This method has been used by the Delaware and Hudson Canal Co. [R. R.].



FIG. 71.

(c) **Iron plates.** An iron plate of the form shown in Fig. 72 (b) is bent and used as shown in Fig. 72 (a). Bolts passing through

the bolt-holes shown secure the plates to the timbers and make a strong joint which may be readily loosened for repairs. By slight modifications in the design the method may be used for inclined posts and complicated joints.



FIG. 72.

(d) **Split caps and sills.** These are described in § 129. Their

advantages apply with even greater force to framed trestles.

(e) **Dowels and drift-bolts.** These joints facilitate cheap and rapid construction, but renewals and repairs are very difficult, it being almost impossible to extract a drift-bolt which has been driven its full length without splitting open the pieces containing it. Notwithstanding this objection they are extensively used, especially for temporary work which is not expected to be used long enough to need repairs.

137. Multiple-story construction. Single-story framed trestle bents are used for heights up to 18 or 20 feet and exceptionally up to 30 feet. For greater heights some such construction as is illustrated in a skeleton design in Fig. 73 is used. By using split sills between each story and separate vertical and batter posts in each story, any piece may readily be removed and

renewed if necessary. The height of these stories varies, in different designs, from 15 to 25 and even 30 feet. In some designs the structure of each story is independent of the stories above and below. This greatly facilitates both the original construction and subsequent repairs. In other designs the verticals and batter-posts are made continuous through two consecutive stories. The structure is somewhat stiffer, but is much more difficult to repair.

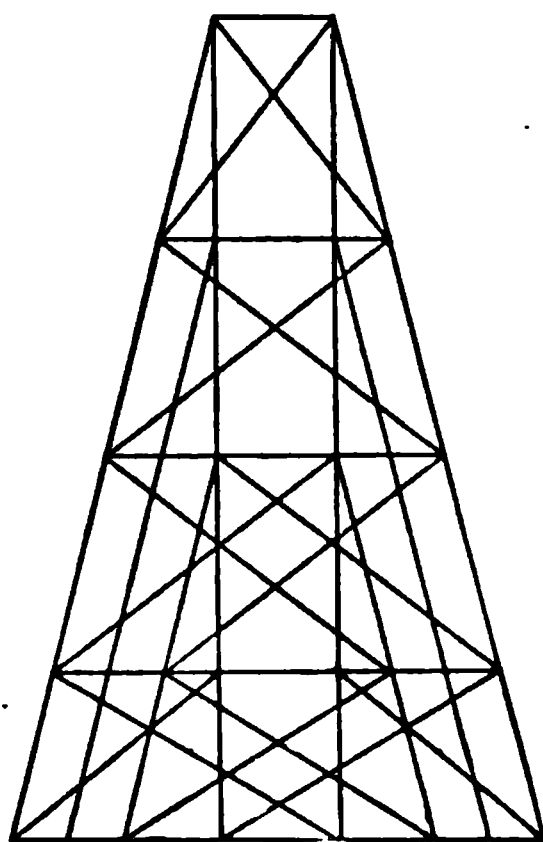


FIG. 73.

Since the bents of any trestle are usually of variable height and those heights are not always an even multiple of the uniform height desired for the stories, it becomes necessary to make the upper stories of uniform height and let

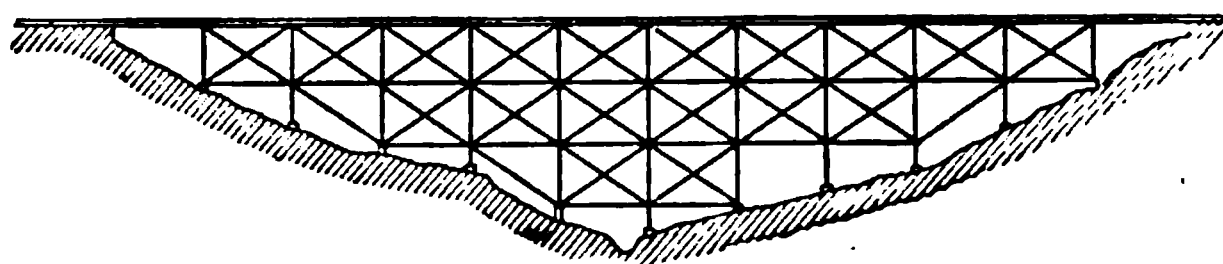


FIG. 74.

the odd amount go to the lowest story, as shown in Figs. 73 and 74.

138. Span. The shorter the span the greater the number of trestle bents; the longer the span the greater the required strength of the stringers supporting the floor. Economy demands the adoption of a span that shall make the sum of these requirements a minimum. The higher the trestle the greater the cost of each bent, and the greater the span that would be justifiable. Nearly all trestles have bents of variable height, but the advantage of employing uniform standard sizes is so great that many roads use the same span and sizes of timber not only for the panels of any given trestle, but also for all trestles

regardless of height. The spans generally used vary from 10 to 16 feet. The Norfolk and Western R. R. uses a span of 12' 6" for all single-story trestles, and a span of 25' for all multiple-story trestles. The stringers are the same in both cases, but when the span is 25 feet, knee-braces are run

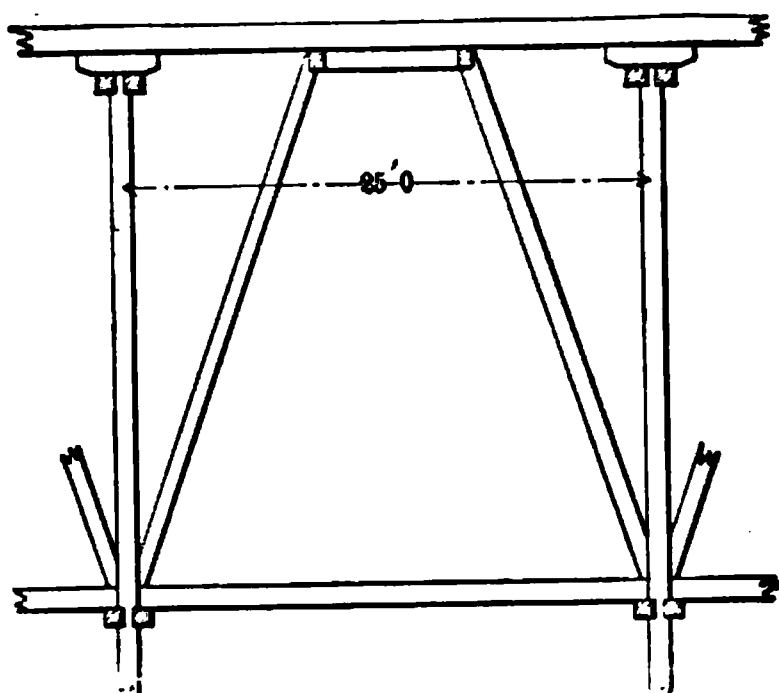


FIG. 75.

from the sill of the first story below to near the middle of each set of stringers. These knee-braces are connected at the top by a "straining-beam" on which the stringers rest, thus supporting the stringer in the center and virtually reducing the span about one-half.

139. Foundations. (a) Piles. Piles are frequently used as a foundation, as in Fig. 76, particularly in soft ground, and also for temporary structures. These foundations are cheap, quickly constructed, and are particularly valuable when it is financially necessary to open the road for traffic as soon as possible and with the least expenditure of money; but there is the disadvantage of inevitable decay within a few years unless the piles are chemically treated, as will be discussed later. Chemical treatment, however, increases the cost so that such a foundation would often cost more than a foundation of stone. A pile should be driven under each post as shown in Fig. 76.

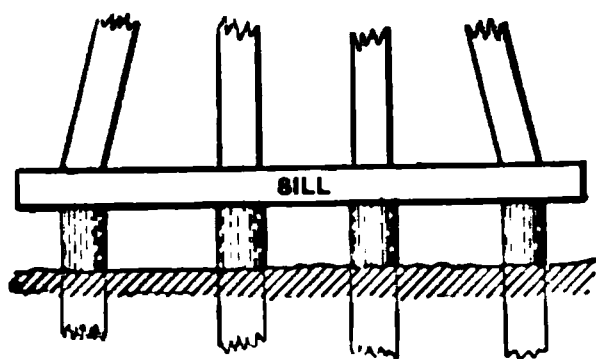


FIG. 76.

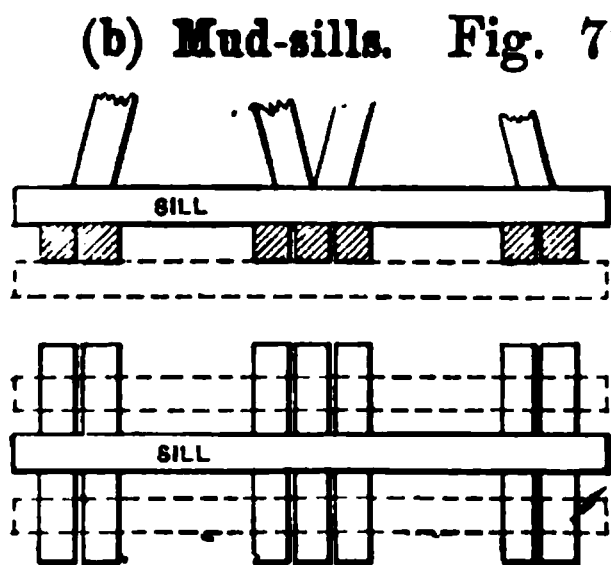


FIG. 77.

(b) **Mud-sills.** Fig. 77 illustrates the use of mud-sills as built by the Louisville and Nashville R. R. Eight blocks $12'' \times 12'' \times 6'$ are used under each bent. When the ground is very soft, two additional timbers ($12'' \times 12'' \times$ length of bent-sill), as shown by the dotted lines, are placed underneath. The number required evidently de-

pends on the nature of the ground.

(c) **Stone foundations.** Stone foundations are the best and the most expensive. For very high trestles the Norfolk and Western R.R. employs foundations as shown in Fig. 78, the

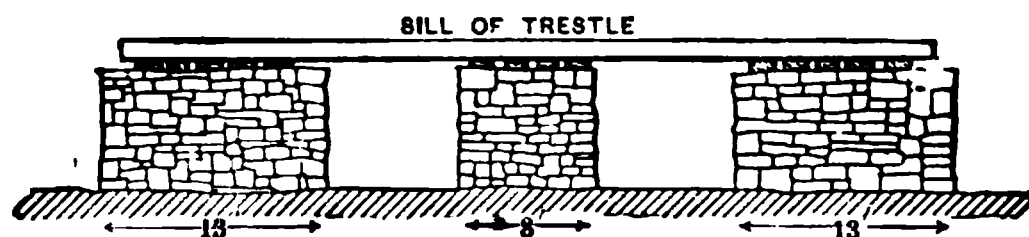


FIG. 78.

walls being 4 feet thick. When the height of the trestle is 72 feet or less (the plans requiring for 72' in height a foundation-wall 39' 6' long) the foundation is made continuous. The sill of the trestle should rest on several short lengths of $3'' \times 12''$ plank, laid transverse to the sill on top of the wall.

140. Longitudinal bracing. This is required to give the structure longitudinal stiffness and also to reduce the columnar length of the posts. This bracing generally consists of horizontal "waling-strips" and diagonal braces. Sometimes the braces are placed wholly on the outside posts unless the trestle is very high. For single-story trestles the P. R. R. employs the "laced" system, i.e., a line of posts joining the cap of one bent with the sill of the next, and the sill of that bent with the cap of the next. Some plans employ braces forming an \times in alternate panels. Connecting these braces in the center more than doubles their columnar strength. Diagonal braces, when bolted to posts, should be fastened to them as near the ends of

the posts as possible. The sizes employed vary largely, depending on the clear length and on whether they are expected to act by tension or compression. 3" \times 12" planks are often used when the design would require tensile strength only, and 8" \times 8" posts are often used when compression may be expected.

141. Lateral bracing. Several of the more recent designs of trestles employ diagonal lateral bracing between the caps of adjacent bents. It adds greatly to the stiffness of the trestle and better maintains its alignment. 6" \times 6" posts, forming an X and connected at the center, will answer the purpose.

142. Abutments. When suitable stone for masonry is at hand and a suitable subsoil for a foundation is obtainable without too much excavation, a masonry abutment will be the best. Such an abutment would probably be used when masonry footings for trestle bents were employed (§ 139, c).

Another method is to construct a "crib" of 10" \times 12" timber, laid horizontally, drift-bolted together, securely braced and embedded into the ground. Except for temporary construction such a method is generally objectionable on account of rapid decay.

Another method, used most commonly for pile trestles, and for framed trestles having pile foundations (§ 139, a), is to use a pile bent at such a place that the natural surface on the *up-hill* side is not far below the cap, and the thrust of the material, filled in to bring the surface to grade, is insignificant. 3" \times 12" planks are placed behind the piles, cap, and stringers to retain the filled material.

FIG. 79.

FLOOR SYSTEMS.

143. Stringers. The general practice is to use two, three, and even four stringers under each rail. Sometimes a stringer

is placed under each guard-rail. Generally the stringers are made of two panel lengths and laid so that the joints alternate. A few roads use stringers of only one panel length, but this practice is strongly condemned by many engineers. The stringers should be separated to allow a circulation of air around them and prevent the decay which would occur if they were placed close together. This is sometimes done by means of 2" planks, 6' to 8' long, which are placed over each trestle bent. Several bolts, passing through all the stringers forming a group and through the separators, bind them all into one solid construction. Cast-iron "spools" or washers, varying from 4" to $\frac{3}{4}$ " in length (or thickness), are sometimes strung on each bolt so as to separate the stringers. Sometimes washers are used between the separating planks and the stringers, the object of the separating planks then being to bind the stringers, especially abutting stringers, and increase their stiffness.

The most common size for stringers is 8" \times 16". The Pennsylvania Railroad varies the width, depth, and number of stringers under each rail according to the clear span. It may be noticed that, assuming a uniform load per running foot, both

Clear span.	No. of pieces under each rail.	Width.	Depth.
10 feet	2	8 inches	15 inches
12 "	2	8 "	16 "
14 "	2	10 "	17 "
16 "	3	8 "	17 "

the pressure per square inch at the ends of the stringers (the caps having a width of 12") and also the stress due to transverse strain are kept *approximately* constant for the variable gross load on these varying spans.

144. Corbels. A corbel (in trestle-work) is a stick of timber (perhaps two placed side by side), about 3' to 6' long, placed underneath and along the stringers and resting on the cap. There are strong prejudices for and against their use, and a

corresponding diversity in practice. They are bolted to the stringers and thus stiffen the joint. They certainly reduce the objectionable crushing of the fibers at each end of the stringer, but if the corbel is no wider than the stringers, as is generally the case, the area of pressure between the corbels and the cap is

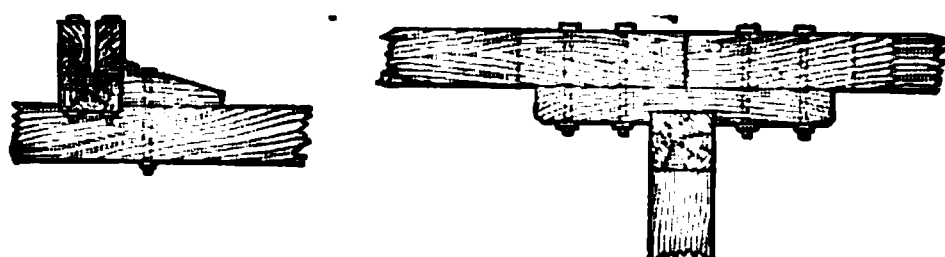


FIG. 80.

no greater and the pressure per square inch on the cap is no less than the pressure on the cap if no corbels were used. If the corbels and cap are made of hard wood, as is recommended by some, the danger of crushing is lessened, but the extra cost and the frequent scarcity of hard wood, and also the extra cost and labor of using corbels, may often neutralize the advantages obtained by their use.

145. Guard-rails. These are frequently made of 5" × 8" stuff, notched 1" for each tie. The sizes vary up to 8" × 8", and the depth of notch from $\frac{3}{4}$ " to 1 $\frac{1}{2}$ ". They are generally bolted to every third or fourth tie. It is frequently specified that they shall be made of oak, white pine, or yellow pine. The joints are made over a tie, by halving each piece, as illustrated in Fig. 81. The joints on opposite sides of the trestle should be



FIG. 81.

“staggered.” Some roads fasten every tie to the guard-rail, using a bolt, a spike, or a lag-screw.

Guard-rails were originally used with the idea of preventing the wheels of a derailed truck from running off the ends of the ties. But it has been found that an outer guard-rail alone (without an inner guard-rail) becomes an actual element of danger, since it has frequently happened that a derailed wheel has caught

on the outer guard-rail, thus causing the truck to slew around and so produce a dangerous accident. The true function of the *outside* guard-rail is thus changed to that of a tie-spacer, which keeps the ties from spreading when a derailment occurs. The inside guard-rail generally consists of an ordinary steel rail spiked about 10 inches inside of the running rail. These inner guard-rails should be bent inward to a point in the center of the track about 50 feet from the end of the bridge or trestle. If the inner guard-rails are placed with a clear space of 10 inches inside the running rail, the outer guard-rails should be *at least* 6' 10" apart. They are generally much farther apart than this.

146. Ties on trestles. If a car is derailed on a bridge or trestle, the heavily loaded wheels are apt to force their way between the ties by displacing them unless the ties are closely spaced and fastened. The clear space between ties is generally equal to or less than their width. Occasionally it is a little more than their width. 6" \times 8" ties, spaced 14" to 16" from center to center, are most frequently used. The length varies from 9' to 12' for single track. They are generally notched $\frac{1}{2}$ " deep on the under side where they rest on the stringers. Oak ties are generally required even when cheaper ties are used on the other sections of the road. Usually every third or fourth tie is bolted to the stringers. When stringers are placed underneath the guard-rails, bolts are run from the top of the guard-rail to the under side of the stringer. The guard-rails thus hold down the whole system of ties, and no direct fastening of the ties to the stringers is needed.

147. Superelevation of the outer rail on curves. The location of curves on trestles should be avoided if possible, especially when the trestle is high. Serious additional strains are introduced especially when the curvature is sharp or the speed high. Since such curves are sometimes practically unavoidable, it is necessary to design the trestle accordingly. If a train is stopped on a curved trestle, the action of the train on the trestle is evidently vertical. If the train is moving with a considerable velocity, the resultant of the weight and the cen-

trifugal action is a force somewhat inclined from the vertical. Both of these conditions may be expected to exist at times. If the *axis* of the system of posts is vertical (as illustrated in methods *a*, *b*, *c*, *d*, and *e*), any lateral force, such as would be produced by a moving train, will tend to rack the trestle bent. If the stringers are set vertically, a centrifugal force likewise tends to tip them sidewise. If the axis of the system of posts (or of the stringers) is inclined so as to coincide with the pressure of the train on the trestle when the train is moving at its normal velocity, there is no tendency to rack the trestle when the train is moving at that velocity, but there will be a tendency to rack the trestle or twist the stringers when the train is stationary. Since a moving train is usually the normal condition of affairs, as well as the condition which produces the maximum stress, an inclined axis is evidently preferable from a theoretical standpoint; but whatever design is adopted, the trestle should evidently be sufficiently cross-braced for either a moving or a stationary load, and any proposed design must be studied as to the effect of *both* of these conditions. Some of the various methods of securing the requisite superelevation may be described as follows:

(a) **Framing the outer posts longer than the inner posts, so that the cap is inclined at the proper angle; axis of posts vertical.** (Fig. 82.) The method requires more work in framing the trestle, but simplifies subsequent track-laying and maintenance, unless it should be found that the superelevation adopted is unsuitable, in which case it could be corrected by one of the other methods given below. The stringers tend to twist when the train is stationary.

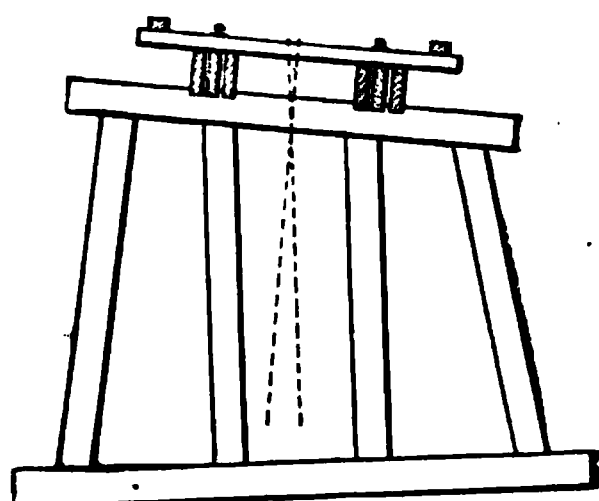


FIG. 82

(b) **Notching the cap so that the stringers are at a different elevation.** (Fig. 83.) This weakens the cap and requires that all ties shall be notched to a bevelled surface to fit the stringers,

which also weakens the ties. A centrifugal force will tend to twist the stringers and rack the trestle.

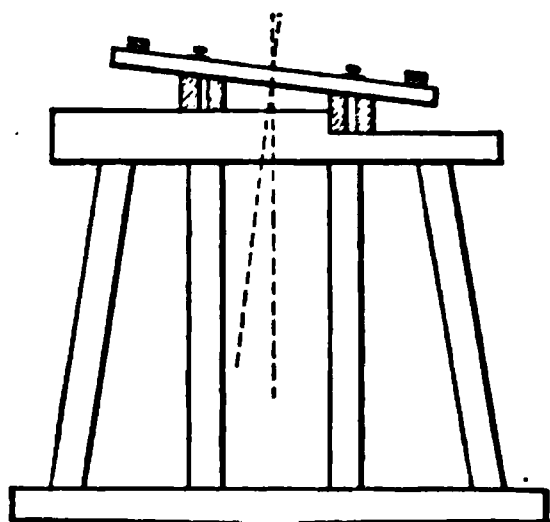


FIG. 83.

(c) **Placing wedges underneath the ties at each stringer.** These wedges are fastened with two bolts. Two or more wedges will be required for each tie. The additional number of pieces required for a long curve will be immense, and the work of inspection and keeping the nuts tight will greatly in-

crease the cost of maintenance.

(d) **Placing a wedge under the outer rail at each tie.** This requires but one extra piece per tie. There is no need of a wedge under the inner tie in order to make the rail normal to the tread. The resulting inward inclination is substantially that produced by some forms of rail-chairs or tie-plates. The spikes (a little longer than usual) are driven through the wedge into the tie. Sometimes "lag-screws" are used instead of spikes. If experience proves that the superelevation is too much or too little, it may be changed by this method with less work than by any other.

(e) **Corbels of different heights.** When corbels are used (see § 144) the required inclination of the floor system may be obtained by varying the depth of the corbels.

(f) **Tipping the whole trestle.** This is done by placing the trestle on an inclined foundation. If very much inclined, the trestle bent must be secured against the possibility of slipping sidewise, for the slope would be considerable with a sharp curve, and the vibration of a moving train would reduce the coefficient of friction to a comparatively small quantity.

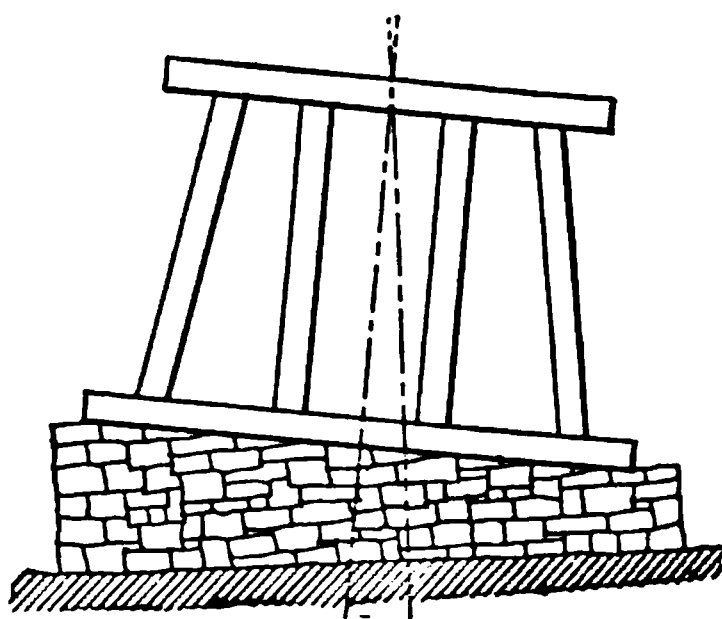


FIG. 84.

(g) **Framing the outer posts longer.** This case is identical

with case (*a*) except that the axis of the system of posts is inclined, as in case (*f*), but the sill is horizontal.

The above-described plans will suggest a great variety of methods which are possible and which differ from the above only in minor details.

148. Protection from fire. Trestles are peculiarly subject to fire, from passing locomotives, which may not only destroy the trestle, but perhaps cause a terrible disaster. This danger is sometimes reduced by placing a strip of galvanized iron along the top of each set of stringers and also along the tops of the caps. Still greater protection was given on a long trestle on the Louisville and Nashville R. R. by making a solid flooring of timber, covered with a layer of ballast on which the ties and rails were laid as usual.

Barrels of water should be provided and kept near all trestles, and on very long trestles barrels of water should be placed every two or three hundred feet along its length. A place for the barrels may be provided by using a few ties which have an extra length of about four feet, thus forming a small platform, which should be surrounded by a railing. The track-walkers should be held accountable for the maintenance of a supply of water in these barrels, renewals being frequently necessary on account of evaporation. Such platforms should also be provided as REFUGE-BAYS for track-walkers and trackmen working on the trestle. On very long trestles such a platform is sometimes provided with sufficient capacity for a hand-car.

149. Timber. Any strong durable timber may be used when the choice is limited, but oak, pine, or cypress are preferred when obtainable. When all of these are readily obtainable, the various parts of the trestle will be constructed of different kinds of wood—the stringers of long-leaf pine, the posts and braces of pine or red cypress, and the caps, sills, and corbels (if used) of white oak. The use of oak (or a similar hard wood) for caps, sills, and corbels is desirable because of its greater strength in resisting crushing across the grain, which is the critical test for these parts. There is no physiological basis to

the objection, sometimes made, that different species of timber, in contact with each other, will rot quicker than if only one kind of timber is used. When a very extensive trestle is to be built at a place where suitable growing timber is at hand but there is no convenient sawmill, it will pay to transport a portable sawmill and engine and cut up the timber as desired.

150. Cost of framed timber trestles. The cost varies widely on account of the great variation in the cost of timber. When a railroad is first penetrating a new and undeveloped region, the cost of timber is frequently small, and when it is obtainable from the company's right-of-way the only expense is felling and sawing. The work per M., B. M., is small, considering that a single stick $12'' \times 12'' \times 25'$ contains 300 feet, B. M., and that sometimes a few hours' work, worth less than \$1, will finish all the work required on it. Smaller pieces will of course require more work per foot, B. M. Long-leaf pine can be purchased from the mills at from \$8 to \$12 per M. feet, B. M., according to the dimensions. To this must be added the freight and labor of erection. The cartage from the nearest railroad to the trestle may often be a considerable item. Wrought iron will cost about 3 c. per pound and cast iron 2 c., although the prices are often lower than these. The amount of iron used depends on the detailed design, but, as an average, will amount to \$1.50 to \$2 per 1000 feet, B. M., of timber. A large part of the trestling of the country has been built at a contract price of about \$30 per 1000 feet, B. M., erected. While the cost will frequently rise to \$40 and even \$50 when timber is scarce, it will drop to \$13 (cost quoted) when timber is cheap.

DESIGN OF WOODEN TRETTLES.

151. Common practice. A great deal of trestling has been constructed without any rational design except that custom and experience have shown that certain sizes and designs are *probably* safe. This method has resulted occasionally in failures but more frequently in a very large waste of timber. Many railroads

PLATE I.

(To face page 174)

employ a uniform size for all posts, caps, and sills, and a uniform size for stringers, all regardless of the height or span of the trestle. For repair work there are practical reasons favoring this. "To attempt to run a large lot of sizes would be more wasteful in the end than to maintain a few stock sizes only. Lumber can be bought more cheaply by giving a general order for 'the run of the mill for the season,' or 'a cargo lot,' specifying approximate percentages of standard stringer size, of 12×12 -inch stuff, 10×10 -inch stuff, etc., and a liberal proportion of 3- or 4-inch plank, all lengths thrown in. The 12×12 -inch stuff, etc., is ordered all lengths, from a certain specified length up. In case of a wreck, washout, burn-out, or sudden call for a trestle to be completed in a stated time, it is much more economical and practical to order a certain number of carloads of 'trestle stuff' to the ground and there to select piece after piece as fast as needed, dependent only upon the length of stick required. When there is time to make the necessary surveys of the ground and calculations of strength, and to wait for a special bill of timber to be cut and delivered, the use of different sizes for posts in a structure would be warranted to a certain extent." * For new construction, when there is generally sufficient time to design and order the proper sizes, such wastefulness is less excusable, and under any conditions it is both safer and more economical to prepare *standard designs* which can be made applicable to varying conditions and which will at the same time utilize as much of the strength of the timber as can be depended on. In the following sections will be given the elements of the preparation of such standard designs, which will utilize uniform sizes with as little waste of timber as possible. It is *not* to be understood that special designs should be made for each individual trestle.

152. Required elements of strength. The *stringers* of trestles are subject to transverse strains, to crushing across the grain at the ends, and to shearing along the neutral axis. The

* From "Economical Designing of Timber Trestle Bridges."

strength of the timber must therefore be computed for all these kinds of stress. *Caps* and *sills* will fail, if at all, by crushing across the grain; although subject to other forms of stress, these could hardly cause failure in the sizes usually employed. There is an apparent exception to this: if piles are improperly driven and an uneven settlement subsequently occurs, it may have the effect of transferring practically all of the weight to two or three piles, while the *cap* is subjected to a severe transverse strain which may cause its failure. Since such action is caused generally by avoidable errors of construction it may be considered as abnormal, and since such a failure will generally occur by a *gradual* settlement, all danger may be avoided by reasonable care in inspection. *Posts* must be tested for their columnar strength. These parts form the bulk of the trestle and are the parts which can be definitely designed from known stresses. The stresses in the bracing are more indefinite, depending on indeterminate forces, since the inclined posts take up an unknown proportion of the lateral stresses, and the design of the bracing may be left to what experience has shown to be safe, without involving any large waste of timber.

153. Strength of timber. Until recently tests of the strength of timber have generally been made by testing small, selected, well-seasoned sticks of "clear stuff," free from knots or imperfections. Such tests would give results so much higher than the vaguely known strength of large unseasoned "commercial" timber that very large factors of safety were recommended—factors so large as to detract from any confidence in the whole theoretical design. Recently the U. S. Government has been making a thoroughly scientific test of the strength of full-size timber under various conditions as to seasoning, etc. The work has been so extensive and thorough as to render possible the economical designing of timber structures.

One important result of the investigation is the determination of the great influence of the moisture in the timber and the law of its effect on the strength. It has been also shown that timber soaked with water has substantially the same

strength as green timber, even though the timber had once been thoroughly seasoned. Since trestles are exposed to the weather they should be designed on the basis of using green timber. It has been shown that the strength of green timber is very regularly about 55 to 60% of the strength of timber in which the moisture is 12% of the dry weight, 12% being the proportion of moisture usually found in timber that is protected from the weather but not heated, as, e.g., the timber in a barn. Since the moduli of rupture have all been reduced to this standard of moisture (12%), if we take *one-eighth* of the rupture values, it still allows a factor of safety of about five, even on green timber.

Moduli of rupture for various timbers. [12% moisture.]
(Condensed from U. S. Forestry Circular, No. 15.)

No.	Species.	Weight per cubic foot.	Cross-bending.		Crush- ing end wise.	Crush- ing across grain.	Shear- ing along grain.
			Ultimate Strength.	Modulus of Elasticity.			
1	Long-leaf pine.....	38	12 600	2 070 000	8000	1180	700
2	Cuban "	39	13 600	2 370 000	8700	1220	700
3	Short-leaf "	32	10 100	1 680 000	6500	960	700
4	Loblolly "	33	11 300	2 050 000	7400	1150	700
5	White "	24	7 900	1 390 000	5400	700	400
6	Red "	31	9 100	1 620 000	6700	1000	500
7	Spruce "	39	10 000	1 640 000	7800	1200	800
8	Bald cypress.....	29	7 900	1 290 000	6000	800	500
9	White cedar.....	28	6 300	910 000	5200	700	400
10	Douglas spruce....	32	7 900	1 680 000	5700	800	500
11	White oak.....	50	13 100	2 090 000	8500	2200	1000
12	Overcup "	46	11 300	1 620 000	7300	1900	1000
13	Post "	50	12 300	2 030 000	7100	3000	1100
14	Cow "	46	11 500	1 610 000	7400	1900	900
15	Red "	45	11 400	1 970 000	7200	2300	1100
16	Texan "	46	13 100	1 860 000	8100	2000	900
19	Willow "	45	10 400	1 750 000	7200	1600	900
20	Spanish "	46	12 000	1 930 000	7700	1800	900
21	Shagbark hickory..	51	16 000	2 390 000	9500	2700	1100
27	Pignut " ..	56	18 700	2 730 000	10900	3200	1200
28	White elm.....	34	10 300	1 540 000	6500	1200	800
29	Cedar "	46	13 500	1 700 000	8000	2100	1300
30	White ash.....	39	10 800	1 640 000	7200	1900	1100

AVERAGE SAFE ALLOWABLE WORKING UNIT STRESSES, IN POUNDS, PER SQUARE INCH. RECOMMENDED BY THE COMMITTEE ON "STRENGTH OF BRIDGE AND TRESTLE TIMBERS." (ASSOCIATION OF RAILWAY SUPERINTENDENTS OF BRIDGES AND BUILDINGS: FIFTH ANNUAL CONVENTION, NEW ORLEANS, OCTOBER, 1895.)

Kind of timber.	Tension.		Compression.				Transverse.		Shearing.	
	With grain.	Across grain.	With grain.			Across grain.	Extreme fibre stress.	Modulus of elasticity.	With grain.	Across grain.
			End bearing.	Column under 15 diameters.						
Ten.	Ten.	Five.	Five.	Four.	Six.	Two.	Four.	Four.		
Factor of safety.....										
White oak	1000	200	1400	900	500	1000	550 000	200	1000	
White pine	700	50	1100	700	200	700	500 000	100	500	
Southern, long-leaf, or Georgia yellow pine	1200	60	1600	1000	350	1200	850 000	150	1250	
Douglas, Oregon, and Wash- } Yellow fir..	1200	...	1600	1200	300	1100	700 000	150	....
ington fir or pine: } Red fir.....	1000	...	....	....	...	800	....	...	....
Northern or short-leaf yellow pine.....	900	50	1200	800	250	1000	600 000	100	1000	
Red pine.....	900	50	1200	800	200	800	600 000	...	....
Norway pine.....	800	...	1200	800	200	700	600 000	...	....
Canadian (Ottawa) white pine.....	1000	...	....	1000	...	...	....	100	....
Canadian (Ontario) red pine	1000	...	....	1000	...	800	700 000	100	....
Spruce and Eastern fir.....	800	50	1200	800	200	700	600 000	100	750	
Hemlock.....	600	...	....	800	150	600	450 000	100	600
Cypress	600	...	1200	800	200	800	450 000	...	....
Cedar.....	800	...	1200	800	200	800	350 000	...	400	
Chestnut.....	900	...	....	1000	250	800	500 000	150	400
California redwood.	700	...	....	800	200	750	350 000	100	....
California spruce.....	....	...	....	800	...	800	600 000	...	....

On page 177 there are quoted the values taken from the U. S. Government reports on the strength of timber, the tests probably being the most thorough and reliable that were ever made.

On page 178 are given the "average safe allowable working unit stresses in pounds per square inch," as recommended by the committee on "Strength of Bridge and Trestle Timbers," the work being done under the auspices of the Association of Railway Superintendents of Bridges and Buildings. The report was presented at their fifth annual convention, held in New Orleans, in October, 1895.

154. Loading. As shown in § 138, the span of trestles is always small, is generally 14 feet, and is never greater than 18' except when supported by knee-braces. The greatest load that will ever come on any one span will be the concentrated loading of the drivers of a consolidation locomotive. With spans of 14 feet or less it is impossible for even the four pairs of drivers to be on the same span at once. The weight of the rails, ties, and guard-rails should be added to obtain the total load on the stringers, and the weight of these, plus the weight of the stringers, should be added to obtain the pressure on the caps or corbels. This dead load is almost insignificant compared with the live load and may be included with it. The weight of rails, ties, etc., may be estimated at 200 pounds per foot. To obtain the weight on the caps the weight of the stringers must be added, which depends on the design and on the weight per cubic foot of the wood employed. But as the weight of the stringers is comparatively small, a considerable percentage of variation in weight will have but an insignificant effect on the result. Disregarding all refinements as to actual dimensions, the ordinary maximum loading for standard gauge railroads may be taken as that due to four pairs of driving-axles, spaced 5' 0" apart and giving a pressure of 25,000 pounds per axle. This should be increased to 40,000 pounds per axle (same spacing) for the heaviest traffic. On the basis of 25,000 pounds per axle the following results have been computed:

STRESSES ON VARIOUS SPANS DUE TO MOVING LOADS OF 25,000 POUNDS,
SPACED 5' 0" APART.

Span in feet.	Max. mom.— ft. lbs.	Max. shear.	Max load on one cap.
10	65 000	38 500	52 100
12	103 600	45 000	62 700
14	142 400	49 600	74 200
16	181 400	54 725	85 700
18	220 600	60 100	97 900

Although the dead load does not vary in proportion to the live load, yet, considering the very small influence of the dead load, there will be no appreciable error in assuming the corresponding values, for a load of 40,000 lbs. per axle, to be $\frac{4}{3}$ of those given in the above tabulation.

155. Factors of safety.—The most valuable result of the government tests is the knowledge that under given moisture conditions the strength of various species of sound timber is not the variable uncertain quantity it was once supposed to be, but that its strength can be relied on to a comparatively close percentage. This confidence in values permits the employment of lower factors of safety than have heretofore been permissible. Stresses, which when excessive would result in immediate destruction, such as cross-breaking and columnar stresses, should be allowed a higher factor of safety—say 6 or 8 for green timber. Other stresses, such as crushing across the grain and shearing along the neutral axis, which will be apparent to inspection before it is dangerous, may be allowed lower factors—say 3 to 5.

156. Design of stringers.—The strength of rectangular beams of equal width varies as the square of the depth; therefore deep beams are the strongest. On the other hand, when any cross-sectional dimension of timber much exceeds 12" the cost is much higher per M., B.M., and it is correspondingly difficult to obtain thoroughly sound sticks, free from wind-shakes, etc. Wind-shakes especially affect the shearing strength. Also, if the required transverse strength is obtained by using high narrow stringers, the area of pressure between the stringers and the

cap may become so small as to induce crushing across the grain. This is a very common defect in trestle design. As already indicated in § 138, the span should vary roughly with the average height of the trestle, the longer spans being employed when the trestle bents are very high, although it is usual to employ the same span throughout any one trestle.

To illustrate, if we select a span of 14 feet, the load on one cap will be 74,200 lbs. If the stringers and cap are made of long-leaf yellow pine, which require the closely determined value of 1180 lbs. per square inch to produce a crushing amounting to 3% of the height on timber with 12% moisture, we may use 200 lbs. per square inch as a safe pressure even for green timber; this will require 371 square inches of surface. If the cap is 12" wide, this will require a width of 31 inches, or say 2 stringers under each rail, each 8 inches wide. For rectangular beams

$$\text{Moment} = \frac{1}{8} R' b h^3.$$

Using for R' the safe value 1575 lbs. per square inch, we have

$$142400 \times 12 = \frac{1}{8} \times 1575 \times 32 \times h^3,$$

from which $h = 15''.9$. If desired, the width may be increased to 9" and the depth correspondingly reduced, which will give similarly $h = 14''.8$, or say 15". This shows that two beams, 9" \times 15", under each rail will stand the transverse bending and have more than enough area for crushing.

The shear per square inch will equal

$$\frac{3}{2} \frac{\text{total shear}}{\text{cross section}} = \frac{3}{2} \frac{49600}{4 \times 9 \times 15} = 138 \text{ lbs. per sq. inch,}$$

which is a safe value, although it should preferably be less. Hence the above combination of dimensions will answer.

The deflection should be computed to see if it exceeds the

somewhat arbitrary standard of $\frac{1}{800}$ of the span. The deflection for *uniform loading* is

$$\Delta = \frac{5 W l^3}{32 b h^3 E},$$

in which l = length in inches;
 W = total load, assumed as uniform;
 E = modulus of elasticity, given as 2,070,000 lbs.

per sq. in. for long-leaf pine, 12% dry, and assumed to be 1,200,000 for green timber. Then

$$\Delta = \frac{5 \times 72800 \times 168^3}{32 \times 36 \times 15^3 \times 1200000} = 0''.37$$

$$\frac{1}{800} \times 168'' = 0''.84,$$

so that the calculated deflection is well within the limit. Of course the loading is not strictly uniform, but even with a liberal allowance the deflection is still safe.

For the heaviest practice (40000 lbs. per axle) these stringer dimensions must be correspondingly increased.

157. Design of posts. Four posts are generally used for single-track work. The inner posts are usually braced by the cross-braces, so that their columnar strength is largely increased; but as they are apt to get more than their share of work, the advantage is compensated and they should be treated as unsupported columns for the total distance between cap and sill in simple bents, or for the height of stories in multiple-story construction. The caps and sills are assumed to have a width of 12''. It facilitates the application of bracing to have the columns of the same width and vary the other dimension as required.

Unfortunately the experimental work of the U. S. Government on timber testing has not yet progressed far enough to establish unquestionably a general relation between the strength of long columns and the crushing strength of short blocks. The

but it is certainly a safe dimension. $12'' \times 6''$ would possibly prove amply safe in practice. One method of allowing for weathering is to disregard the outer half-inch on all sides of the post, i.e., to calculate the strength of a post one inch smaller in each dimension than the post actually employed. On this basis an $8'' \times 12'' \times 20'$ post, computed as a $7'' \times 11'$ post, would have a *safe* columnar strength of 706 lbs. per square inch. With an area of 77 square inches, this gives a working load of 54362 lbs. for *each post*, or 217448 lbs. for the four posts. Considering that 74200 lbs. is the maximum load on one cap (14 feet span), the great excess of strength is apparent.

158. Design of caps and sills. The stresses in caps and sills are very indefinite, except as to crushing across the grain. As the stringers are placed almost directly over the inner posts, and as the sills are supported just under the posts, the transverse stresses are almost insignificant. In the above case four posts have an area of $4 \times 12'' \times 8'' = 384$ sq. in. The total load, 74200 lbs., will then give a pressure of 193 pounds per square inch, which is within the allowable limit. This one feature might require the use of $8'' \times 12''$ posts rather than $6'' \times 12''$ posts, for the smaller posts, although probably strong enough as posts, would produce an objectionably high pressure.

159. Bracing. Although some idea of the stresses in the bracing could be found from certain assumptions as to wind-pressure, etc., yet it would probably not be found wise to decrease, for the sake of economy, the dimensions which practice has shown to be sufficient for the work. The economy that would be possible would be too insignificant to justify any risk. Therefore the usual dimensions, given in §§ 139 and 140, should be employed.

CHAPTER V.

TUNNELS.

SURVEYING.

160. Surface surveys. As tunnels are always dug from each end and frequently from one or more intermediate shafts, it is necessary that an accurate surface survey should be made between the two ends. As the natural surface in a locality where a tunnel is necessary is almost invariably very steep and rough, it requires the employment of unusually refined methods of work to avoid inaccuracies. It is usual to run a line on the surface that will be at every point vertically over the center line of the tunnel. Tunnels are generally made straight unless curves are absolutely necessary, as curves add greatly to the cost. Fig. 85 represents roughly a longitudinal section of the

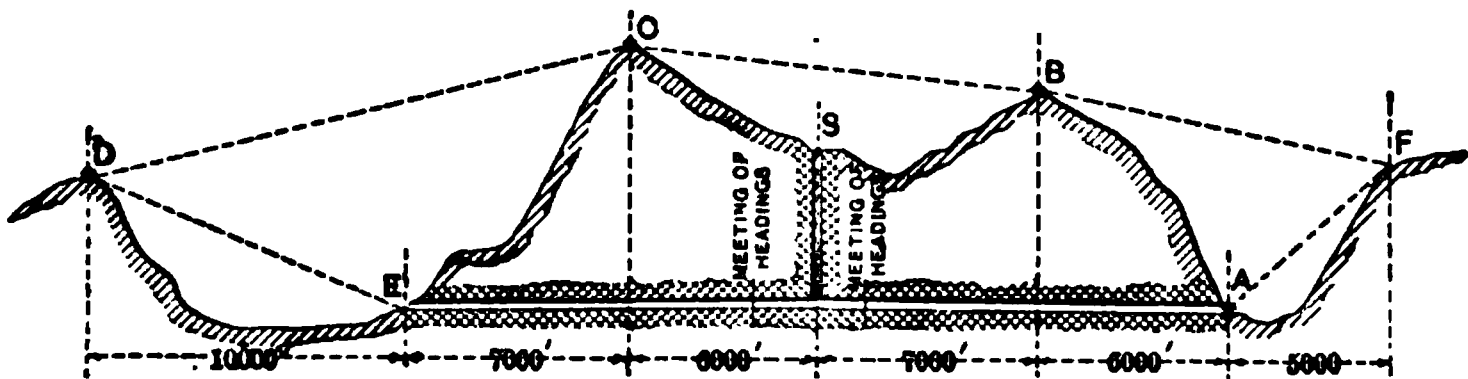


FIG. 85.—SKETCH OF SECTION OF THE HOOSAC TUNNEL.

Hoosac Tunnel. Permanent stations were located at *A*, *B*, *C*, *D*, *E*, and *F*, and stone houses were built at *A*, *B*, *C*, and *D*. These were located with ordinary field transits at first, and then all the points were placed as nearly as possible in one vertical plane by repeated trials and minute corrections, using a very large specially constructed transit. The stations *D* and *F* were necessary because *E* and *A* were invisible from *C* and *B*.

The alignment at *A* and *E* having been determined with great accuracy, the true alignment was easily carried into the tunnel.

The relative elevations of *A* and *E* were determined with great accuracy. Steep slopes render necessary many settings of the level per unit of horizontal distance and require that the work be unusually accurate to obtain even fair accuracy per unit of distance. The levels are usually re-run many times until the probable error is a very small quantity.

The exact horizontal distance between the two ends of the tunnel must also be known, especially if the tunnel is on a grade. The usual steep slopes and rough topography likewise render accurate horizontal measurements very difficult. Frequently when the slope is steep the measurement is best obtained by measuring along the slope and allowing for grade. This may be very accurately done by employing two tripods (level or transit tripods serve the purpose very well), setting them up slightly less than one tape-length apart and measuring between horizontal needles set in wooden blocks inserted in the top of each tripod. The elevation of each needle is also observed. The true horizontal distance between two successive positions of the needles then equals the square root of the difference of the squares of the inclined distance and the difference of elevation. Such measurements will probably be more accurate than those made by attempting to hold the tape horizontal and plumbing down with plumb-bobs, because (1) it is practically difficult to hold both ends of the tape truly horizontal; (2) on steep slopes it is impossible to hold the downhill end of a 100-foot tape (or even a 25-foot length) on a level with the other end, and the great increase in the number of applications of the unit of measurement very greatly increases the probable error of the whole measurement; (3) the vibrations of a plumb-bob introduce a large probability of error in transferring the measurement from the elevated end of the tape to the ground, and the increased number of such applications of the unit of measurement still further increases the probable error.

181. Surveying down a shaft. If a shaft is sunk, as at *S*, Fig. 85, and it is desired to dig out the tunnel in both directions from the foot of the shaft so as to meet the headings from the outside, it is necessary to know, when at the bottom of the shaft, the elevation, alignment, and horizontal distance from each end of the tunnel.

The *elevation* is generally carried down a shaft by means of a steel tape. This method involves the least number of applications of the unit of measurement and greatly increases the accuracy of the final result.

The *horizontal distance from each end* may be easily transferred down the shaft by means of a plumb-bob, using some of the precautions described in the next paragraph.

To transfer the *alignment* from the surface to the bottom of a shaft requires the highest skill because the shaft is always small, and to produce a line perhaps several thousand feet long in a direction given by two points 6 or 8 feet apart requires that the two points must be determined with extreme accuracy. The eminently successful method adopted in the Hoosac Tunnel will be briefly described: Two beams were securely fastened across the top of the shaft (1030 feet deep), the beams being placed transversely to the direction of the tunnel and as far apart as possible and yet allow plumb-lines, hung from the intersection of each beam with the tunnel center line, to swing freely at the bottom of the shaft. These intersections of the beams with the center line were determined by averaging the results of a large number of careful observations for alignment. Two fine parallel wires, spaced about $\frac{1}{16}$ " apart, were then stretched between the beams so that the center line of the tunnel bisected at all points the space between the wires. Plumb-bobs, weighing 15 pounds, were suspended by fine wires beside each cross-beam, the wires passing between the two parallel alignment wires and bisecting the space. The plumb-bobs were allowed to swing in pails of water at the bottom. Drafts of air up the shaft required the construction of boxes surrounding the wires. Even these precautions did not suffice

to absolutely prevent vibration of the wire at the bottom through a very small arc. The mean point of these vibrations in each case was then located on a rigid cross-beam suitably placed at the bottom of the shaft and at about the level of the roof of the tunnel. Short plumb-lines were then suspended from these points whenever desired; a transit was set (by trial) so that its line of collimation passed through both plumb lines and the line at the bottom could thus be prolonged.

162. Underground surveys. Survey marks are frequently placed on the timbering, but they are apt to prove unreliable on account of the shifting of the timbering due to settlement of the surrounding material. They should never be placed at the bottom of the tunnel on account of the danger of being disturbed or covered up. Frequently holes are drilled in the roof and filled with wooden plugs in which a hook is screwed exactly on line. Although this is probably the safest method, even these plugs are not always undisturbed, as the material, unless very hard, will often settle slightly as the excavation proceeds. When a tunnel is perfectly straight and not too long, alignment-points may be given as frequently as desired from permanent stations located *outside* the tunnel where they are not liable to disturbance. This has been accomplished by running the alignment through

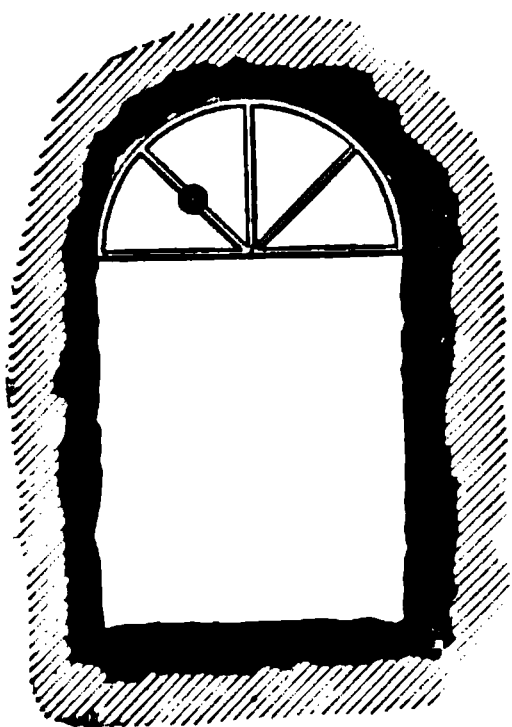


FIG. 86.

the upper part of the cross-section, at one side of the center, where it is out of the way of the piles of masonry material, débris, etc., which are so apt to choke up the lower part of the cross-section. The position of this line relative to the cross-section being fixed, the alignment of any required point of the cross-section is readily found by means of a light frame or template with a fixed target located where this line would intersect the frame when properly placed. A level-bubble on the frame will assist in setting the frame in its proper position.

In all tunnel surveying the cross-wires must be illuminated

by a lantern, and the object sighted at must also be illuminated. A powerful dark-lantern with the opening covered with *ground glass* has been found useful. This may be used to illuminate a plumb-bob string or a very fine rod, or to place behind a brass plate having a narrow slit in it, the axis of the slit and plate being coincident with the plumb-bob string by which it is hung.

On account of the interference to the surveying caused by the work of construction and also by the smoke and dust in the air resulting from the blasting, it is generally necessary to make the surveys at times when construction is temporarily suspended.

163. Accuracy of tunnel surveying. Apart from the very natural desire to do surveying which shall check well, there is an important financial side to accurate tunnel surveying. If the survey lines do not meet as desired when the headings come together, it may be found necessary, if the error is of appreciable size, to introduce a slight curve, perhaps even a reversed curve, into the alignment, and it is even conceivable that the tunnel section would need to be enlarged somewhat to allow for these curves. The cost of these changes and the perpetual annoyance due to an enforced and undesirable alteration of the original design will justify a considerable increase in the expenses of the survey. Considering that the cost of surveys is usually but a small fraction of the total cost of the work, an increase of 10 or even 20% in the cost of the surveys will mean an insignificant addition to the total cost and frequently, if not generally, it will result in a saving of many times the increased cost. The accuracy actually attained in two noted American tunnels is given as follows: The Musconetcong tunnel is about 5000 feet long, bored through a mountain 400 feet high. The error of alignment at the meeting of the headings was 0'.04, error of levels 0'.015, error of distance 0'.52. The Hoosac tunnel is over 25,000 feet long. The heading from the east end met the heading from the central shaft at a point 11274 feet from the east end and 1563 feet from the shaft. The error in alignment was $\frac{5}{16}$ of an inch, that of levels "a few hundredths,"

error of distance "trifling." The alignment, corrected at the shaft, was carried on through and met the heading from the west end at a point 10138 feet from the west end and 2056 feet from the shaft. Here the error of alignment was $\frac{9}{16}$ " and that of levels 0.134 ft.

DESIGN.

164. Cross-sections. Nearly all tunnels have cross-sections peculiar to themselves—all varying at least in the details. The *general* form of a great many tunnels is that of a rectangle surmounted by a semi-circle or semi-ellipse. In very soft material an inverted arch is necessary along the bottom. In such cases the sides will generally be arched instead of vertical. The sides are frequently battered. With very long tunnels, several forms of cross-section will often be used in the same tunnel, owing to differences in the material encountered. In solid rock, which will not disintegrate upon exposure, no lining is required, and the cross-section will be the irregular section left by the blasting, the only requirement being that no rock shall be left within the required cross-sectional figure. Farther on, in the same tunnel, when passing through some very soft treacherous material, it may be necessary to put in a full arch lining—top, sides, and bottom—which will be nearly circular in cross-section. For an illustration of this see Figs. 87 and 88.

The width of tunnels varies as greatly as the designs. Single-track tunnels generally have a width of 15 to 16 feet. Occasionally they have been built 14 feet wide, and even less, and also up to 18 feet, especially when on curves. 24 to 26 feet is the most common width for double track. Many double-track tunnels are only 22 feet wide, and some are 28 feet wide. The heights are generally 19 feet for single track and 20 to 22 feet for double track. The variations from these figures are considerable. The lower limits depend on the cross-section of the rolling stock, with an indefinite allowance for clearance and ventilation. Cross-sections which coincide too closely with what is

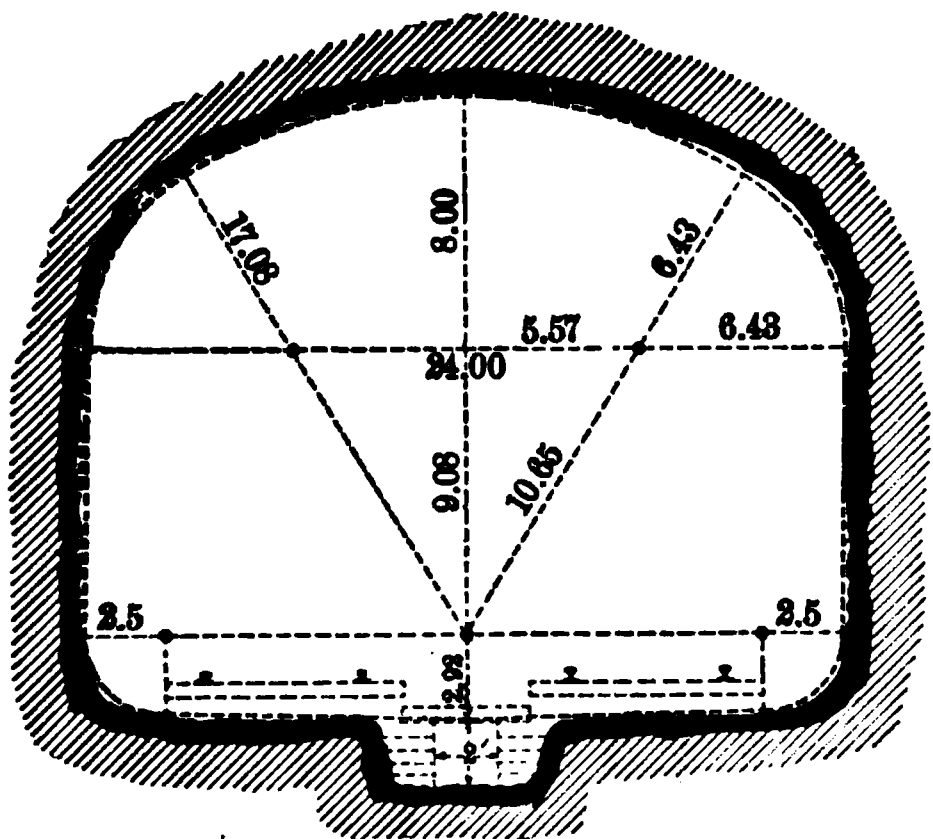


FIG. 87.—HOOSAC TUNNEL. SECTION THROUGH SOLID ROCK.

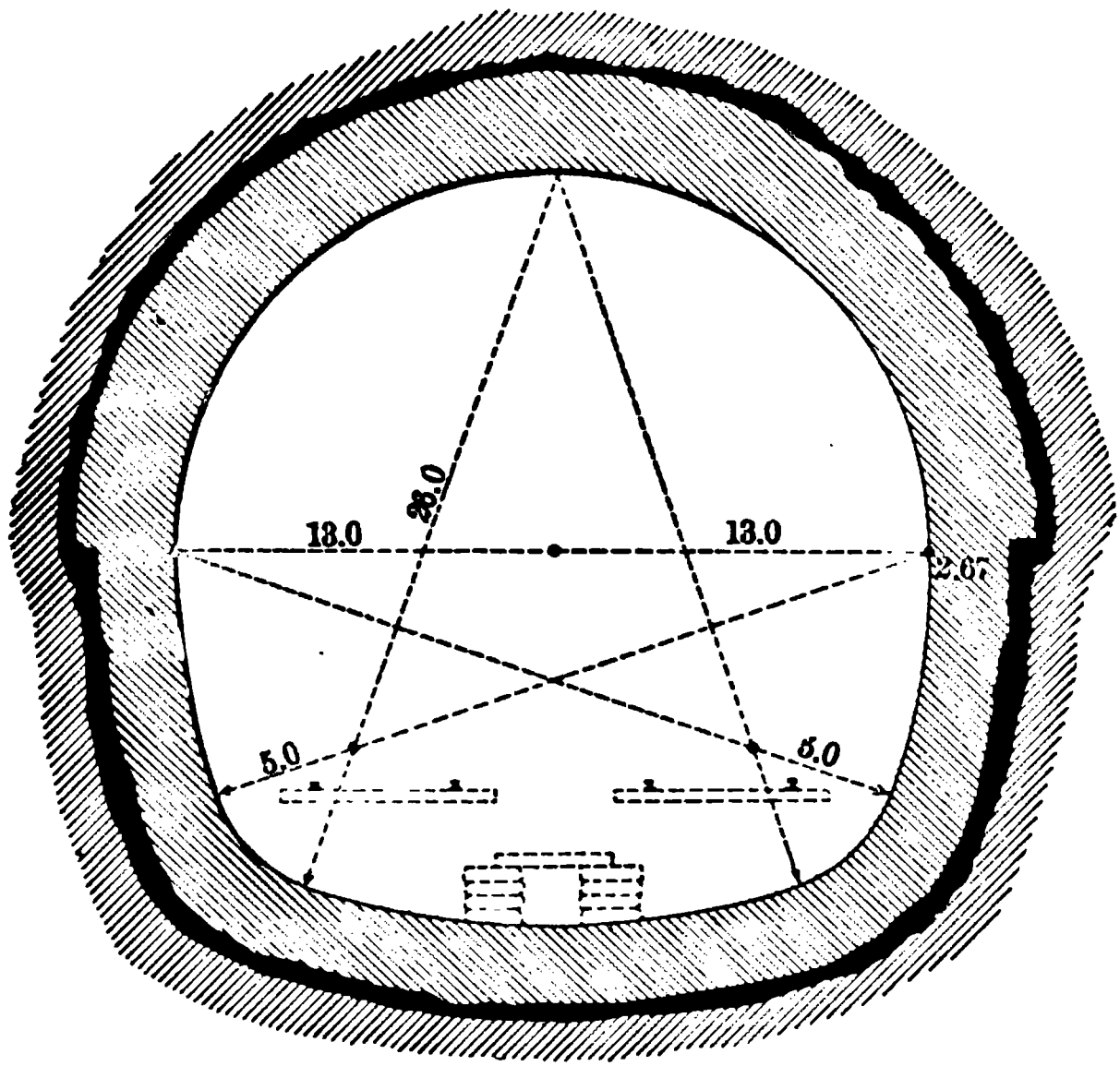


FIG. 88.—HOOSAC TUNNEL. SECTION THROUGH SOFT GROUND.

absolutely required for clearance are objectionable, because any slight settlement of the lining which would otherwise be harmless would then become troublesome and even dangerous. Figs. 87, 88, and 89 * show some typical cross-sections.

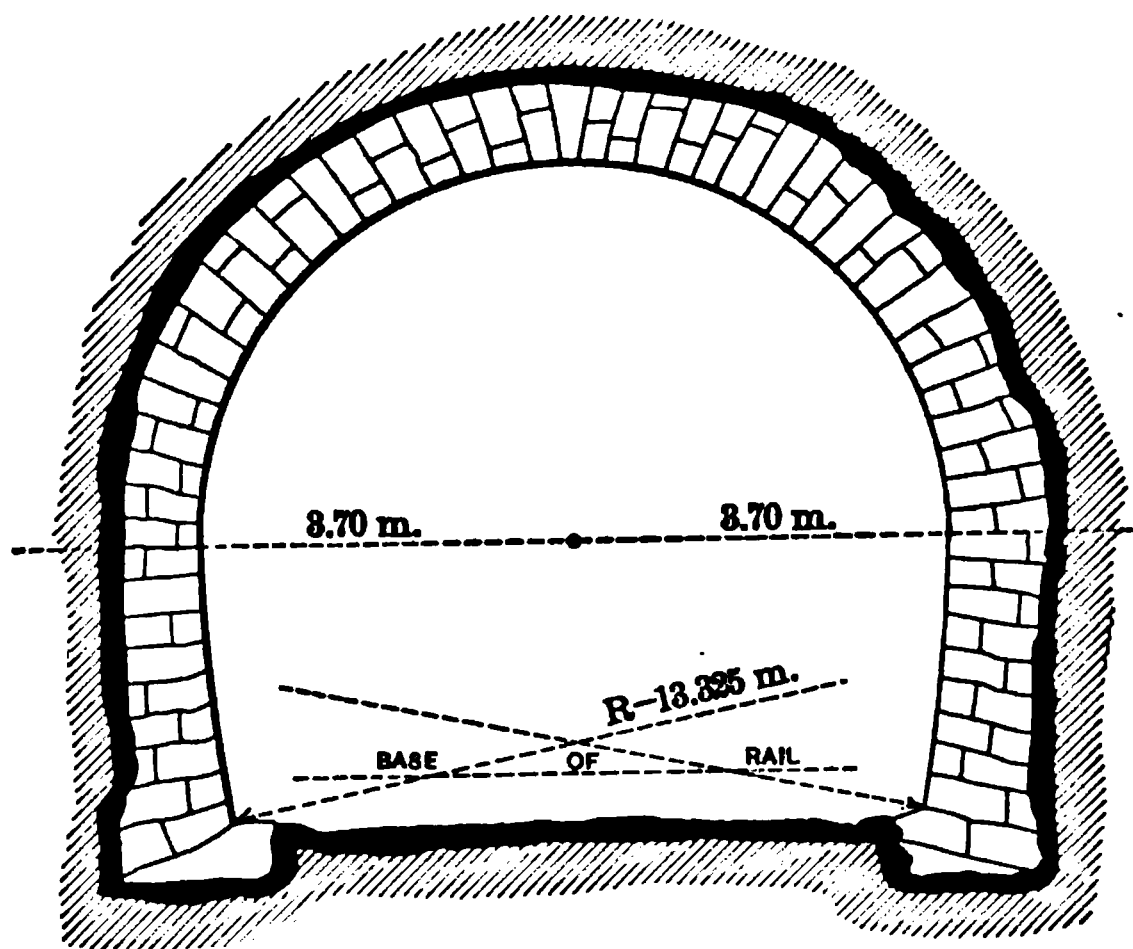


FIG. 89.—ST. CLOUD TUNNEL.

165. Grade. A grade of at least 0.2% is needed for drainage. If the tunnel is at the summit of two grades, the tunnel grade should be practically level, with an allowance for drainage, the actual summit being perhaps in the center so as to drain both ways. When the tunnel forms part of a long ascending grade, it is advisable to reduce the grade through the tunnel unless the tunnel is very short. The additional atmospheric resistance and the decreased adhesion of the driver wheels on the damp rails in a tunnel will cause an engine to work very hard and still more rapidly vitiate the atmosphere until the accumulation of poisonous gases becomes a source of actual danger to the engineer and fireman of the locomotive and of extreme discomfort to the passengers. If the nominal ruling grade of the road were maintained through a tunnel, the maximum resistance would be

* Drinker's "Tunneling."

PLATE II.

TUNNEL-TIMBERING—ENGLISH SYSTEM (a).

TUNNEL-TIMBERING—ENGLISH SYSTEM (b).
(To face page 192.)

PLATE III.

TUNNEL-TIMBERING—ENGLISH SYSTEM (c).

TUNNEL-TIMBERING—ENGLISH SYSTEM (d).
(To face page 192.)

found in the tunnel. This would probably cause trains to stall there, which would be objectionable and perhaps dangerous.

166. Lining. It is a characteristic of many kinds of rock and of all earthy material that, although they may be self-sustaining when first exposed to the atmosphere, they rapidly disintegrate and require that the top and perhaps the sides and even the bottom shall be lined to prevent caving in. In this country, when timber is cheap, it is occasionally framed as an arch and used as the *permanent* lining, but masonry is always to be preferred. Frequently the cross-section is made extra large so that a masonry lining may subsequently be placed inside the wooden lining and thus postpone a large expense until the road is better able to pay for the work. In very soft unstable material, like quicksand, an arch of cut stone voussoirs may be necessary to withstand the pressure. A good quality of brick is occasionally used for lining, as they are easily handled and make good masonry if the pressure is not excessive. Only the best of cement mortar should be used, economy in this feature being the worst of folly. Of course the excavation must include the outside line of the lining. Any excavation which is made outside of this line (by the fall of earth or loose rock or by excessive blasting) must be refilled with stone well packed in. Occasionally it is necessary to fill these spaces with concrete. Of course it is not necessary that the lining be uniform throughout the tunnel.

167. Shafts. Shafts are variously made with square, rectangular, elliptical, and circular cross-sections. The rectangular cross-section, with the longer axis parallel with the tunnel, is most usually employed. Generally the shaft is directly over the center of the tunnel, but that always implies a complicated connection between the linings of the tunnel and shaft, provided such linings are necessary. It is easier to sink a shaft near to one side of the tunnel and make an opening through the nearly vertical side of the tunnel. Such a method was employed in the Church Hill Tunnel, illustrated in Fig. 90.* Fig. 91 † shows

* Drinker's "Tunneling."

† Ržiha, "Lehrbuch der Gesammten Tunnelbaukunst."

a cross-section for a large main shaft. Many shafts have been built with the idea of being left open permanently for ventilation and have therefore been elaborately lined with masonry.

FIG. 90.—CONNECTION WITH SHAFT, CHURCH HILL TUNNEL.

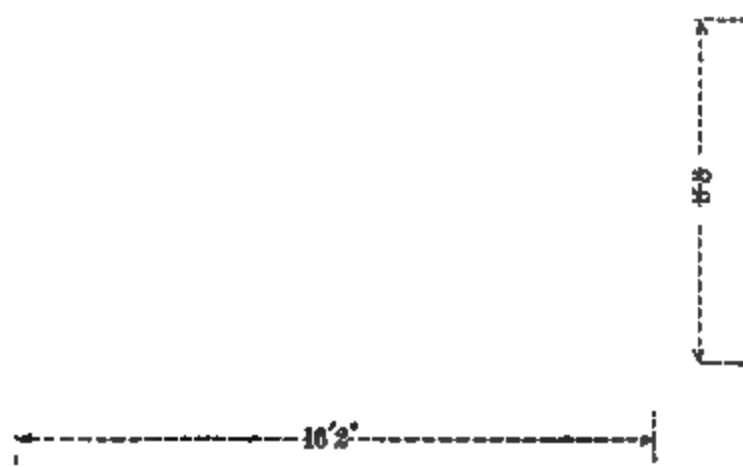


FIG. 91.—CROSS-SECTION. LARGE MAIN SHAFT.

The general consensus of opinion now appears to be that shafts are worse than useless for ventilation; that the quick passage of a train through the tunnel is the most effective ventilator; and that shafts only tend to produce cross-currents and are ineffective to clear the air. In consequence, many of these elaborately lined shafts have been permanently closed, and the more recent

PLATE IV.

TUNNEL-TIMBERING—FRENCH SYSTEM (a).

TUNNEL-TIMBERING—FRENCH SYSTEM (b).
(To face page 194.)

PLATE V.

TUNNEL-TIMBERING—BELGIAN SYSTEM (c).

TUNNEL-TIMBERING—BELGIAN SYSTEM (b).
(To face page 194.)

practice is to close up a shaft as soon as the tunnel is completed. Shafts always form drainage-wells for the material they pass through, and sometimes to such an extent that it is a serious matter to dispose of the water that collects at the bottom, requiring the construction of large and expensive drains.

168. Drains. A tunnel will almost invariably strike veins of water which will promptly begin to drain into the tunnel and not only cause considerable trouble and expense during construction, but necessitate the provision of permanent drains for its perpetual disposal. These drains must frequently be so large as to appreciably increase the required cross-section of the tunnel. Generally a small open gutter on each side will suffice for this purpose, but in double-track tunnels a large covered drain is often built between the tracks. It is sometimes necessary to thoroughly grout the outside of the lining so that water will not force its way through the masonry and perhaps injure it, but may freely drain down the sides and pass through openings in the side walls near their base into the gutters.

CONSTRUCTION.

169. Headings. The methods of all tunnel excavation depend on the general principle that all earthy material, except the softest of liquid mud and quicksand, will be self-sustaining over a greater or less area and for a greater or less time after excavation is made, and the work consists in excavating some material and immediately propping up the exposed surface by timbering and poling-boards. The excavation of the cross-section begins with cutting out a "heading," which is a small horizontal drift whose breast is constantly kept 15 feet or more in advance of the full cross-sectional excavation. In solid self-sustaining rock, which will not decompose upon exposure to air, it becomes simply a matter of excavating the rock with the least possible expenditure of time and energy. In soft ground the heading must be heavily timbered, and as the heading is gradually enlarged the timbering must be gradually extended

and perhaps replaced, according to some regular system, so that when the full cross-section has been excavated it is supported by such timbering as is intended for it. The heading is sometimes made on the center line near the top; with other plans,

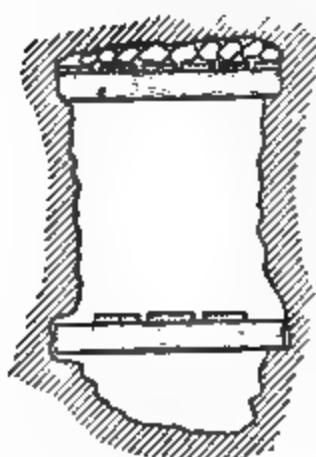


FIG. 92.

on the center line near the bottom; and sometimes two simultaneous headings are run in the two lower corners. Headings near the bottom serve the purpose of draining the material above it and facilitating the excavation. The simplest case of heading timbering is that shown in Fig. 92, in which cross-timbers are placed at intervals just under the roof, set in notches cut in the side walls and supporting poling-boards which sustain whatever pressure may come on them. Cross-timbers near the bottom support a flooring on which vehicles for transporting material may be run and under which the drainage may freely escape. As the necessity for timbering becomes greater, side timbers and even bottom timbers must be added, these timbers supporting poling-boards, and even the breast of the heading must be protected by boards suitably braced, as shown in Fig. 93. The

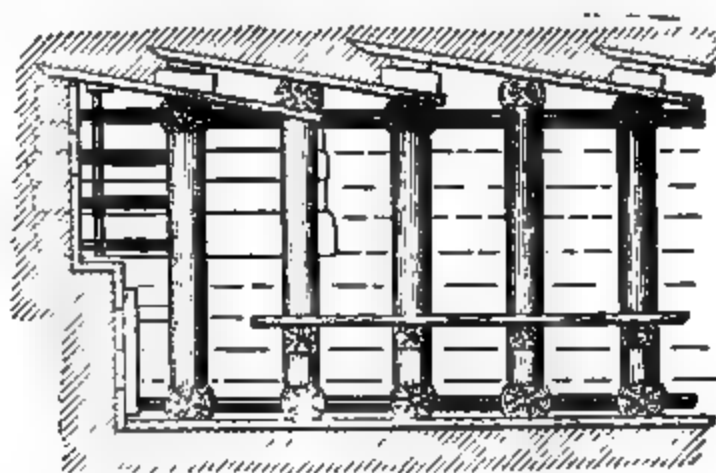


FIG. 93 —TIMBERING FOR TUNNEL HEADING.

supporting timbers are framed into collars in such a manner that added pressure only increases their rigidity.

170. Enlargement. Enlargement is accomplished by removing the poling-boards, one at a time, excavating a greater or less

PLATE VI.

TUNNEL TIMBERING—GERMAN SYSTEM (a).

TUNNEL-TIMBERING—GERMAN SYSTEM (b).
(To face page 198.)

PLATE VII.

TUNNEL-TIMBERING—GERMAN SYSTEM (c).

TUNNEL-TIMBERING—GERMAN SYSTEM (d)

(To face page 196.)

amount of material, and immediately supporting the exposed material with poling-boards suitably braced. (See Figs. 93 and 94.) This work being systematically done, space is thereby



FIG. 94.

obtained in which the framing for the full cross-section may be gradually introduced. The framing is constructed with a cross-section so large that the masonry lining may be constructed within it.

171. Distinctive features of various methods of construction. There are six general systems, known as the English, German, Belgian, French, Austrian, and American. They are so named from the origin of the methods, although their use is not confined to the countries named. Fig. 95 shows by numbers (1 to 5) the order of the excavation within the cross-sections. The English, Austrian, and American systems are alike in excavating the entire cross-section before beginning the construction of the masonry lining. The German method leaves a solid core (5) until practically the whole of the lining is complete. This has the disadvantage of extremely cramped quarters for work, poor ventilation, etc. The Belgian and French methods agree in excavating the upper part of the section, building the arch at once, and supporting it temporarily until the side walls are built. The Belgian method then takes out the core (3), removes very short sections of the sides (4), immediately underpinning the arch with short sections of the side walls and thus gradually constructing the whole side wall. The French method digs out the sides (3), supporting the arch temporarily with timbers and

then replacing the timbers with masonry; the core (4) is taken out last. The French method has the same disadvantage as the German—working in a cramped space. The Belgian and French systems have the disadvantage that the arch, supported temporarily on timber, is very apt to be strained and cracked by the slight settlement that so frequently occurs in soft material. The English, Austrian, and American methods differ mainly in the

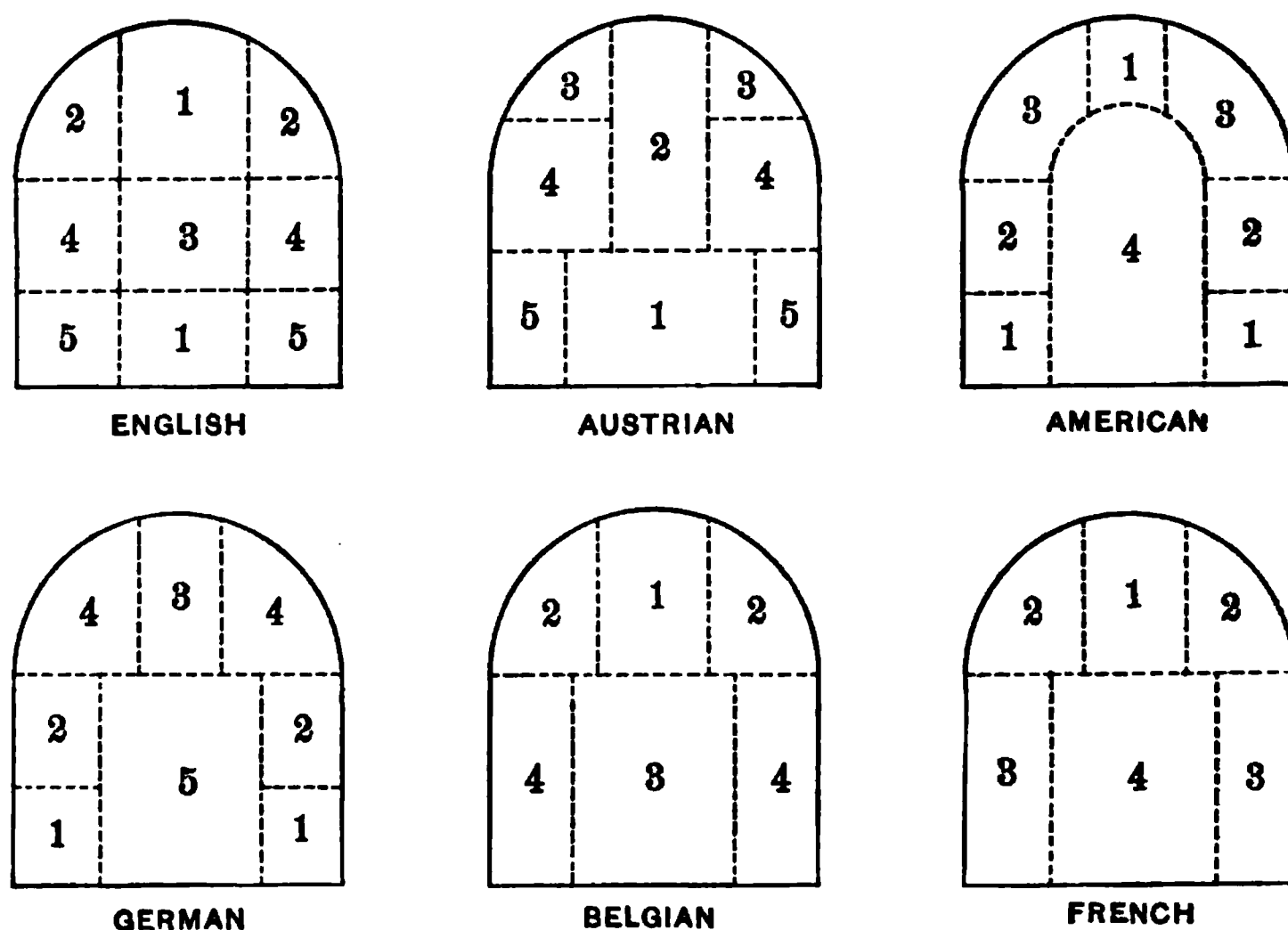


FIG. 95.—ORDER OF WORKING BY THE VARIOUS SYSTEMS.

design of the timbering. The English support the roof by lines of very heavy *longitudinal* timbers which are supported at comparatively wide intervals by a heavy framework occupying the whole cross-section. The Austrian system uses such frequent cross-frames of timber-work that poling-boards will suffice to support the material between the frames. The American system agrees with the Austrian in using frequent cross-frames supporting poling-boards, but differs from it in that the "cross-frames" consist simply of arches of 3 to 15 wooden voussoirs, the voussoirs being blocks of 12" \times 12" timber about 2 to 8 feet long and cut with joints normal to the arch. These arches are put together on a centering which is removed as soon as the arch

PLATE VIII.

TUNNEL-TIMBERING—AUSTRIAN SYSTEM (a).

3
2
1

TUNNEL-TIMBERING—AUSTRIAN SYSTEM (b).

TUNNEL-TIMBERING—AUSTRIAN SYSTEM (c).
(To face page 193)

PLATE IX.

TUNNEL-TIMBERING—AUSTRIAN SYSTEM (d).

TUNNEL-TIMBERING—AUSTRIAN SYSTEM (e).
(To face page 198.)

PLATE X.

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TUNNEL-TIMBERING—AUSTRIAN SYSTEM (f).

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TUNNEL-TIMBERING—AUSTRIAN SYSTEM (g).
(To face page 108)

is keyed up and thus immediately opens up the full cross-section, so that the center core (4) may be immediately dug out and the masonry constructed in a large open space. The American system has been used successfully in very soft ground, but its advantages are greater in loose rock, when it is much cheaper than the other methods which employ more timber. Fig. 90 illustrates the use of the American system. The figure shows the wooden arch in place. The masonry arch may be placed when convenient, since it is *possible* to lay the track and commence traffic as soon as the wooden arch is in place. Plates II to XIV illustrate the methods of excavating and timbering by these various systems.

172. Ventilation during construction. Tunnels of any great length must be artificially ventilated during construction. If the excavated material is rock so that blasting is necessary, the need for ventilation becomes still more imperative. The invention of compressed-air drills simultaneously solved two difficulties. It introduced a motive power which is unobjectionable in its application (as gas would be), and it also furnished at the same time a supply of just what is needed—pure air. If no blasting is done (and sometimes even when there is blasting), air must be supplied by direct pumping. The cooling effect of the sudden expansion of compressed air only reduces the otherwise objectionably high temperature sometimes found in tunnels. Since pure air is being continually pumped in, the foul air is thereby forced out.

173. Excavation for the portals. Under normal conditions there is always a greater or less amount of open cut preceding and following a tunnel. Since all tunnel methods depend (to some slight degree at least) on the capacity of the exposed material to act as an arch, there is implied a considerable thickness of material above the tunnel. This thickness is reduced to nearly zero over the tunnel portals and therefore requires special treatment, particularly when the material is very soft. Fig. 96 *

* Ržiha, "Lehrbuch der Gersamnten Tunnelbaukunst."

illustrates one method of breaking into the ground at a portal. The loose stones are piled on the framing to give stability to the framing by their weight and also to retain the earth on the slope above. Another method is to sink a temporary shaft to the tunnel near the portal; immediately enlarge to the full size and build the masonry lining; then work back to the portal.



FIG. 96.—TIMBERING FOR TUNNEL PORTAL.

This method is more costly, but is preferable in very treacherous ground, it being less liable to cause landslides of the surface material.

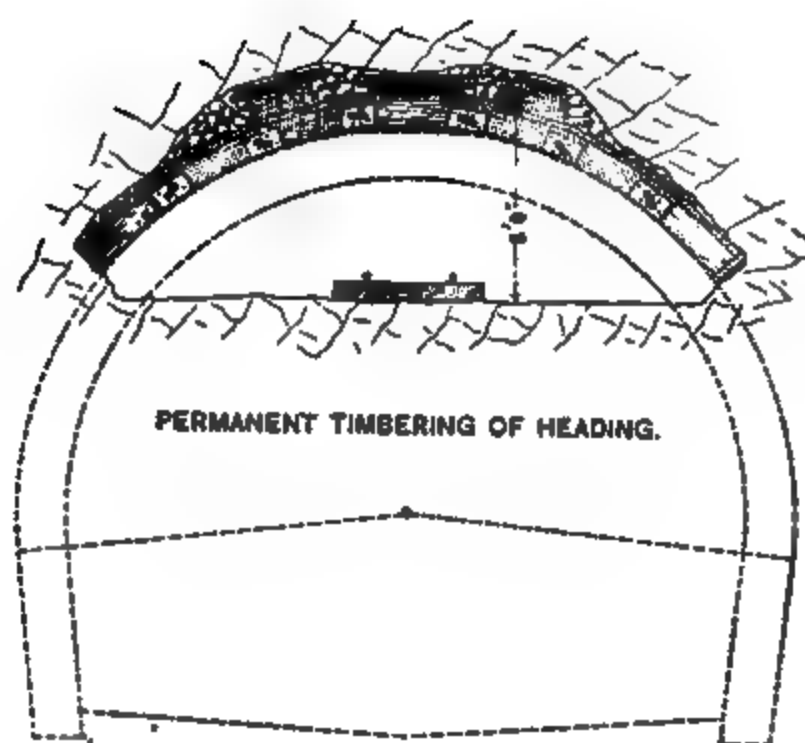
174. Tunnels vs. open cuts. In cases in which an open cut rather than a tunnel is a possibility the ultimate consideration is generally that of first cost combined with other financial considerations and annual maintenance charges directly or indirectly connected with it. Even when an open cut may be constructed at the same cost as a tunnel (or perhaps a little cheaper) the tunnel may be preferable under the following conditions:

1. When the soil indicates that the open cut would be liable to landslides.

2. When the open cut would be subject to excessive snow-drifts or avalanches.

3. When land is especially costly or it is desired to run under existing costly or valuable buildings or monuments. When running through cities, tunnels are sometimes constructed as open cuts and then arched over.

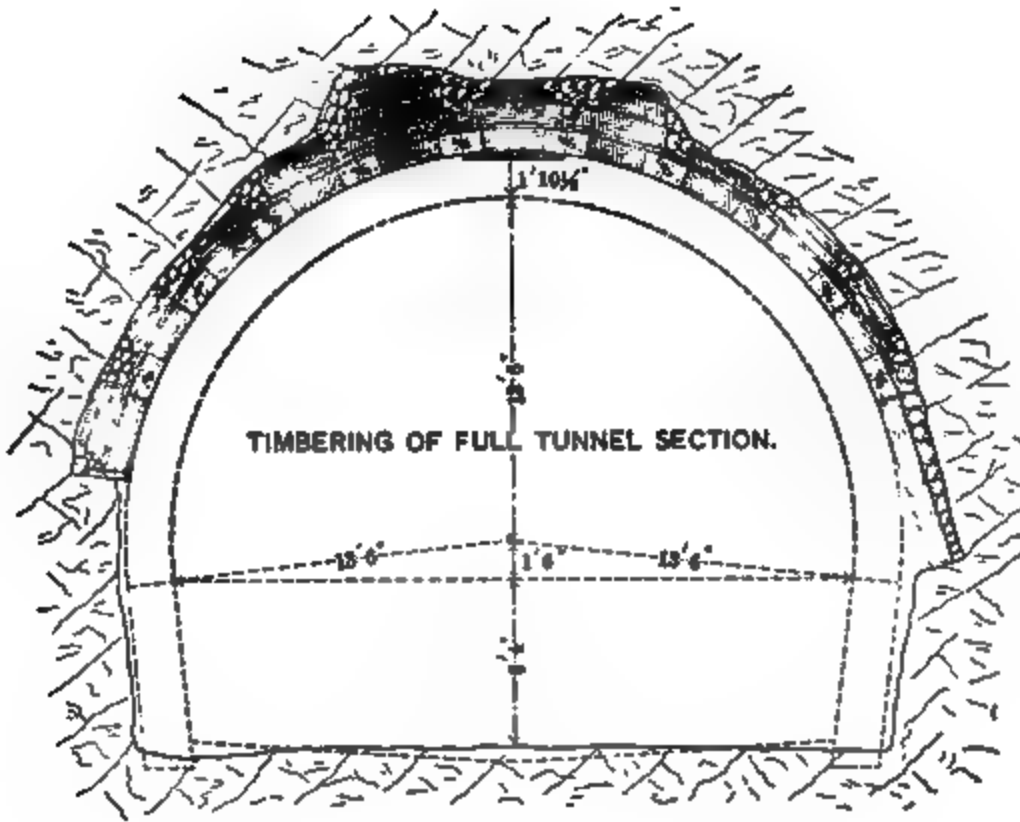
PLATE XI.



PHOENIXVILLE TUNNEL. P. S. V. R.R.

(To face page 200.)

PLATE XII.



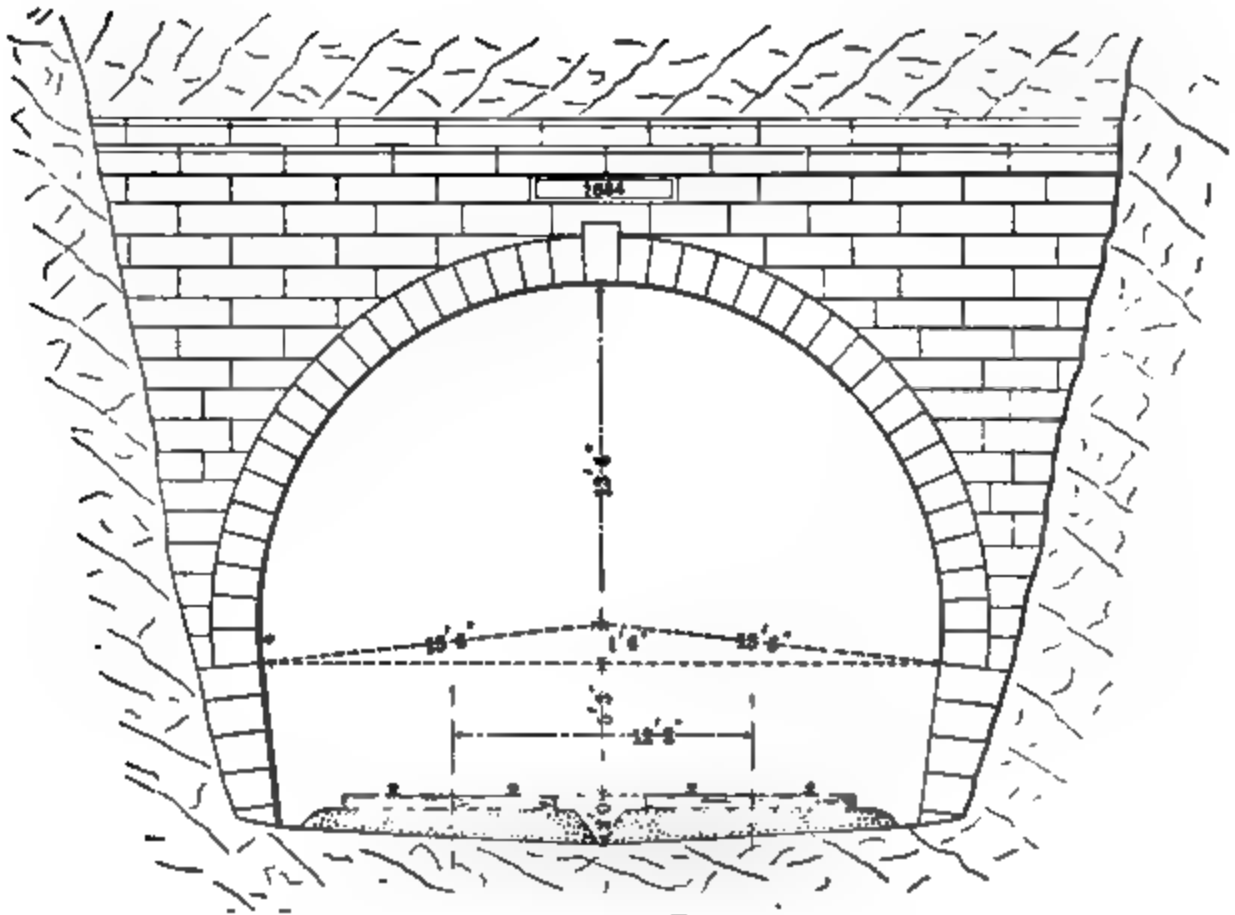
PHOENIXVILLE TUNNEL. P. S. V. R.R.
(To face page 200.)

PLATE XIII.

PHOENIXVILLE TUNNEL. P. S. V. R.R.

(To face page 200.)

PLATE XIV.



ELEVATION OF PORTAL.

LONGITUDINAL SECTION OF PORTAL.
PHOENIXVILLE TUNNEL. P. S. V. R.R.

(To face page 200.)

These cases apply to tunnels *vs.* open cuts when the alignment is fixed by other considerations than the mere topography. The broader question of excavating tunnels to avoid excessive grades or to save distance or curvature, and similar problems, are hardly susceptible of general analysis except as questions of railway economics and must be treated individually.

175. Cost of tunneling. The cost of any construction which involves such uncertainties as tunneling is very variable. It depends on the material encountered, the amount and kind of timbering required, on the size of the cross-section, on the price of labor, and especially on the *reconstruction* that *may* be necessary on account of mishaps.

Headings generally cost \$4 to \$5 per cubic yard for excavation, while the remainder of the cross-section in the same tunnel may cost about half as much. The average cost of a large number of tunnels in this country may be seen from the following table: *

Material.	Cost per cubic yard.				Cost per lineal foot.	
	Excavation.		Masonry.		Single.	Double.
	Single.	Double.	Single.	Double.		
Hard rock.	\$5.89	\$5.45	\$12.00	\$ 8.25	\$ 69.76	\$142.82
Loose rock.	3.12	3.48	9.07	10.41	80.61	119.26
Soft ground.	3.62	4.64	15.00	10.50	185.31	174.42

A considerable variation from these figures may be found in individual cases, due sometimes to unusual skill (or the lack of it) in prosecuting the work, but the figures will generally be sufficiently accurate for preliminary estimates or for the comparison of two proposed routes.

* Figures derived from Drinker's "Tunneling."

CHAPTER VI.

CULVERTS AND MINOR BRIDGES.

176. Definition and object. Although a variable percentage of the rain falling on any section of country soaks into the ground and does not immediately reappear, yet a very large percentage flows over the surface, always seeking and following the lowest channels. The roadbed of a railroad is constantly intersecting these channels, which frequently are normally dry. In order to prevent injury to railroad embankments by the impounding of such rainfall, it is necessary to construct waterways through the embankment through which such rainflow may freely pass. Such waterways, called culverts, are also applicable for the bridging of very small although perennial streams, and therefore in this work the term culvert will be applied to all water-channels passing through a railroad embankment which are not of sufficient magnitude to require a special structural design, such as is necessary for a large masonry arch or a truss bridge.

177. Elements of the design. A well-designed culvert must afford such free passage to the water that it will not "back up" over the adjoining land nor cause any injury to the embankment or culvert. The ability of the culvert to discharge freely all the water that comes to it evidently depends chiefly on the area of the waterway, but also on the form, length, slope, and materials of construction of the culvert and the nature of the approach and outfall. When the embankment is very low and the amount of water to be discharged very great, it sometimes becomes necessary to allow the water to discharge "under a head," i.e.,

with the surface of the water above the top of the culvert. Safety then requires a much stronger construction than would otherwise be necessary to avoid injury to the culvert or embankment by washing. The necessity for such construction should be avoided if possible.

AREA OF THE WATERWAY.

178. Elements involved. The determination of the required area of the waterway involves such a multiplicity of indeterminate elements that any close determination of its value from purely theoretical considerations is a practical impossibility. The principal elements involved are:

a. Rainfall. The real test of the culvert is its capacity to discharge without injury the flow resulting from the extraordinary rainfalls and "cloud bursts" that may occur once in many years. Therefore, while a knowledge of the average annual rainfall is of very little value, a record of the maximum rainfall during heavy storms for a long term of years may give a relative idea of the maximum demand on the culvert.

b. Area of watershed. This signifies the total area of country draining into the channel considered. When the drainage area is very small it is sometimes included within the area surveyed by the preliminary survey. When larger it is frequently possible to obtain its area from other maps with a percentage of accuracy sufficient for the purpose. Sometimes a special survey for the purpose is considered justifiable.

c. Character of soil and vegetation. This has a large influence on the rapidity with which the rainflow from a given area will reach the culvert. If the soil is hard and impermeable and the vegetation scant, a heavy rain will run off suddenly, taxing the capacity of the culvert for a short time, while a spongy soil and dense vegetation will retard the flow, making it more nearly uniform and the maximum flow at any one time much less.

d. Shape and slope of watershed. If the watershed is very long and narrow (other things being equal), the water from the

remoter parts will require so much longer time to reach the culvert that the flow will be comparatively uniform, especially when the slope of the whole watershed is very low. When the slope of the remoter portions is quite steep it may result in the nearly simultaneous arrival of a storm-flow from all parts of the watershed, thus taxing the capacity of the culvert.

e. Effect of design of culvert. The principles of hydraulics show that the slope of the culvert, its length, the form of the cross-section, the nature of the surface, and the form of the approach and discharge all have a considerable influence on the area of cross-section required to discharge a given volume of water in a given time, but unfortunately the combined hydraulic effect of these various details is still a very uncertain quantity.

179. Methods of computation of area. There are three possible methods of computation.

(a) Theoretical. As shown above it is a practical impossibility to estimate correctly the combined effect of the great multiplicity of elements which influence the final result. The nearest approach to it is to estimate by the use of empirical formulæ the amount of water which will be presented at the upper end of the culvert in a given time and then to compute, from the principles of hydraulics, the rate of flow through a culvert of given construction, but (as shown in § 178, *e*) such methods are still very unreliable, owing to lack of experimental knowledge. This method has *apparently* greater scientific accuracy than other methods, but a little study will show that the elements of uncertainty are as great and the final result no more reliable. The method is most reliable for streams of uniform flow, but it is under these conditions that method (*c*) is most useful. The theoretical method will not therefore be considered further.

(b) Empirical. As illustrated in § 180, some formulæ make the area of waterway a function of the drainage area, the formula being affected by a coefficient the value of which is estimated between limits according to the judgment. Assuming that the formulæ are sound, their use only narrows the limits of

error, the final determination depending on experience and judgment.

(c) **From observation.** This method, considered by far the best for permanent work, consists in observing the high-water marks on contracted channel-openings which are on the same stream and as near as possible to the proposed culvert. If the country is new and there are no such openings, the wisest plan is to bridge the opening by a temporary structure in wood which has an ample waterway (see § 126, *b*, 4) and carefully observe all high-water marks on that opening during the 6 to 10 years which is ordinarily the minimum life of such a structure. As shown later, such observations may be utilized for a close computation of the required waterway. Method (*b*) may be utilized for an approximate calculation for the required area for the temporary structure, using a value which is intentionally excessive, so that a permanent structure of sufficient capacity may subsequently be constructed *within* the temporary structure.

180. Empirical formulæ. Two of the best known empirical formulæ for area of the waterway are the following:

(a) **Myer's formula:**

Area of waterway in square feet = $C \times \sqrt{\text{drainage area in acres}}$, where C is a coefficient varying from 1 for flat country to 4 for mountainous country and rocky ground. As an illustration, if the drainage area is 100 acres, the waterway area should be from 10 to 40 square feet, according to the value of the coefficient chosen. It should be noted that this formula does not regard the great variations in rainfall in various parts of the world nor the design of the culvert, and also that the final result depends largely on the choice of the coefficient.

(b) **Talbot's formula:**

Area of waterway in square feet = $C \times \sqrt{(\text{drainage area in acres})^3}$.
 “For steep and rocky ground C varies from $\frac{2}{3}$ to 1. For rolling agricultural country subject to floods at times of melting snow, and with the length of the valley three or four times its width, C is about $\frac{1}{3}$; and if the stream is longer in proportion to the area, decrease C . In districts not affected by accumulated snow, and

where the length of the valley is several times the width, $\frac{1}{8}$ or $\frac{1}{4}$, or even less, may be used. C should be increased for steep side slopes, especially if the upper part of the valley has a much greater fall than the channel at the culvert." * As an illustration, if the drainage area is 100 acres the area of waterway should be $C \times 31.6$. The area should then vary from 5 to 31 square feet, according to the character of the country. Like the previous estimate, the result depends on the choice of a coefficient and disregards local variations in rainfall, except as they may be arbitrarily allowed for in choosing the coefficient.

181. Value of empirical formulæ. The fact that these formulæ, as well as many others of similar nature that have been suggested, depend so largely upon the choice of the coefficient shows that they are valuable "more as a guide to the judgment than as a working rule," as Prof. Talbot explicitly declares in commenting on his own formula. In short, they are chiefly valuable in indicating a probable maximum and minimum between which the true result probably lies.

182. Results based on Observation. As already indicated in § 179, observation of the stream in question gives the most reliable results. If the country is new and no records of the flow of the stream during heavy storms has been taken, even the life of a temporary wooden structure may not be long enough to include one of the unusually severe storms which must be allowed for, but there will usually be some high-water mark which will indicate how much opening will be required. The following quotation illustrates this: "A tidal estuary may generally be safely narrowed considerably from the extreme water lines if stone revetments are used to protect the bank from wash. Above the true estuary, where the stream cuts through the marsh, we generally find nearly vertical banks, and we are safe if the faces of abutments are placed even with the banks. In level sections of the country, where the current is sluggish, it is usually safe to encroach somewhat on the

* Prof. A. N. Talbot, "Selected Papers of the Civil Engineers' Club of the Univ. of Illinois."

general width of the stream, but in rapid streams among the hills the width that the stream has cut for itself through the soil should not be lessened, and in ravines carrying mountain torrents the openings must be left very much larger than the ordinary appearance of the banks of the stream would seem to make necessary.” *

As an illustration of an observation of a storm-flow through a temporary trestle, the following is quoted: “Having the flood height and velocity, it is an easy matter to determine the volume of water to be taken care of. I have one ten-bent pile trestle 135 feet long and 24 feet high over a spring branch that ordinarily runs about six cubic inches per second. Last summer during one of our heavy rainstorms (four inches in less than three hours) I visited this place and found by float observations the surface velocity at the highest stage to be 1.9 feet per second. I made a high-water mark, and after the flood-water receded found the width of stream to be 12 feet and an average depth of $2\frac{1}{2}$ feet. This, with a surface velocity of 1.9 feet per second, would give approximately a discharge of 50 cubic feet, or 375 gallons, per second. Having this information it is easy to determine size of opening required.” †

183. Degree of accuracy required. The advantages resulting from the use of standard designs for culverts (as well as other structures) have led to the adoption of a comparatively small number of designs. The practical use made of a computation of required waterway area is to determine which one of several standard designs will most nearly fulfill the requirements. For example, if a 24-inch iron pipe, having an area of 3.14 square feet, is considered to be a little small, the next size (30-inch) would be adopted; but a 30-inch pipe has an area of 4.92 square feet, which is 56% larger. A similar result, except that the percentage of difference might not be quite so marked,

* J. P. Snow, Boston & Maine Railway. From Report to Association of Railway Superintendents of Bridges and Buildings. 1897.

† A. J. Kelley, Kansas City Belt Railway. From Report to Association of Railway Superintendents of Bridges and Buildings. 1897.

will be found by comparing the areas of consecutive standard designs for stone box culverts.

The advisability of designing a culvert to withstand any storm-flow that may *ever* occur is considered doubtful. Several years ago a record-breaking storm in New England carried away a very large number of bridges, etc., hitherto supposed to be safe. It was not afterward considered that the design of those bridges was faulty, because the extra cost of constructing bridges capable of withstanding such a flood, added to interest for a long period of years, would be enormously greater than the cost of repairing the damages of such a storm once or twice in a century. Of course the element of danger has some weight, but not enough to justify a great additional expenditure, for common prudence would prompt unusual precautions during or immediately after such an extraordinary storm.

✱

PIPE CULVERTS.

184. Advantages. Pipe culverts, made of cast iron or earthenware, are very durable, readily constructed, moderately cheap, will pass a larger volume of water in proportion to the area than many other designs on account of the smoothness of the surface, and (when using iron pipe) may be used very close to the track when a low opening of large capacity is required. Another advantage lies in the ease with which they may be inserted through a somewhat larger opening that has been temporarily lined with wood, without disturbing the roadbed or track.

185. Construction. Permanency requires that the foundation shall be firm and secure against being washed out. To accomplish this, the soil of the trench should be hollowed out to fit the lower half of the pipe, making suitable recesses for the bells. In very soft treacherous soil a foundation-block of concrete is sometimes placed under each joint, or even throughout the whole length. When pipes are laid through a slightly larger timber culvert great care should be taken that the pipes are properly supported, so that there will be no settling nor

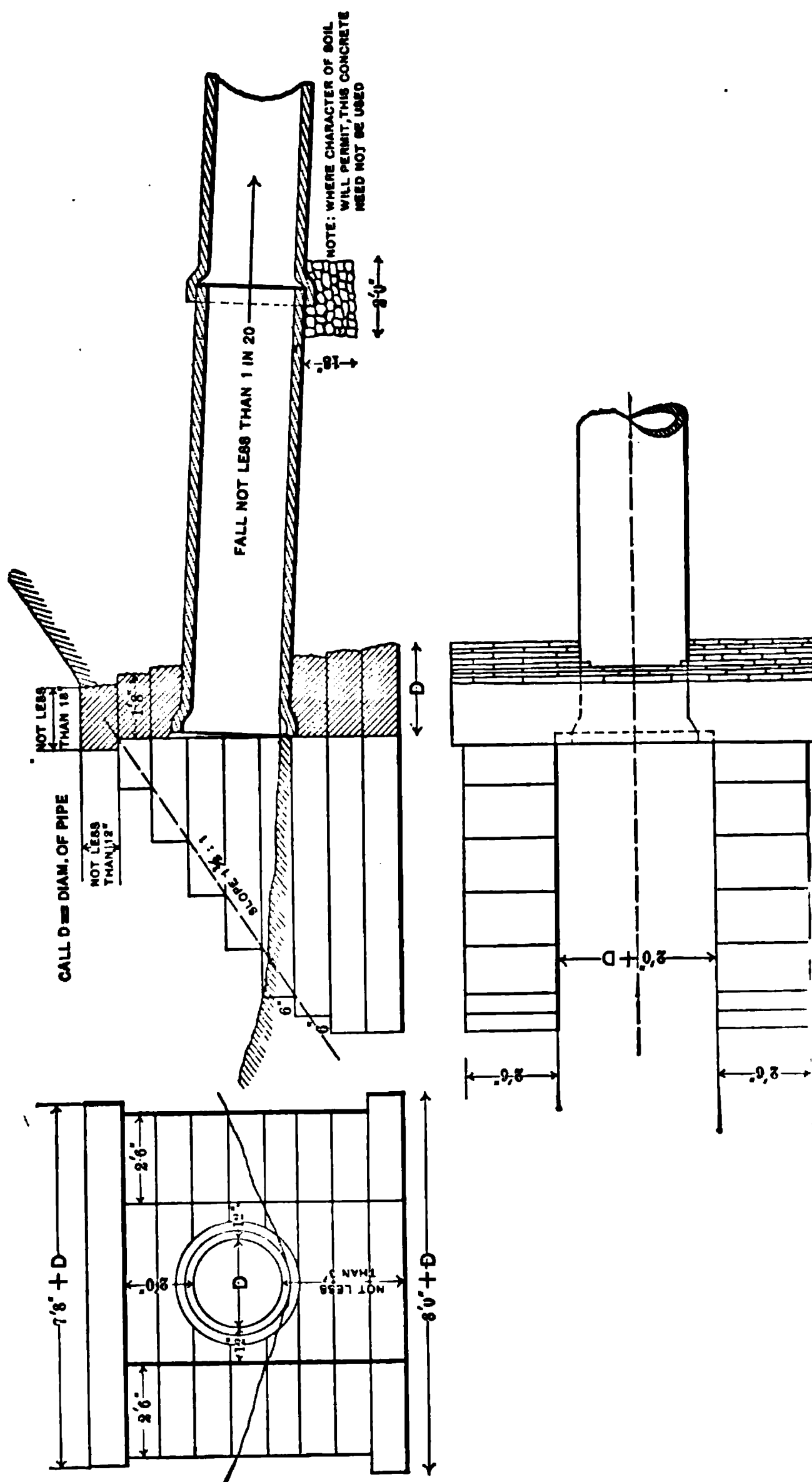
development of unusual strains when the timber finally decays and gives way. To prevent the washing away of material around the pipe the ends should be protected by a bulkhead. This is best constructed of masonry (see Fig. 97), although wood is sometimes used for cheap and minor constructions. The joints should be calked, especially when the culvert is liable to run full or when the outflow is impeded and the culvert is liable to be partly or wholly filled during freezing weather. The cost of a calking of clay or even hydraulic cement is insignificant compared with the value of the additional safety afforded. When the grade of the pipe is perfectly uniform, a very low rate of grade will suffice to drain a pipe culvert, but since some unevenness of grade is inevitable through uneven settlement or imperfect construction, a grade of 1 in 20 should preferably be required, although much less is often used. The length of a pipe culvert is approximately determined as follows:

$$\text{Length} = 2s \text{ (depth of embankment to top of pipe) } + \text{(width of roadbed)},$$

in which s is the slope ratio (horizontal to vertical) of the banks. In practice an even number of lengths will be used which will most nearly agree with this formula.

186. Iron-pipe culverts. Simple cast-iron pipes are used in sizes from 12" to 48" diameter. These are usually made in lengths of 12 feet with a few lengths of 6 feet, so that any required length may be more nearly obtained. The lightest pipes made are sufficiently strong for the purpose, and even those which would be rejected because of incapacity to withstand pressure may be utilized for this work. In Fig. 97 are shown the standard plans used on the C. C. C. & St. L. Ry., which may be considered as typical plans.

Pipes formed of cast-iron segments have been used up to 12 feet diameter. The shell is then made comparatively thin, but is stiffened by ribs and flanges on the outside. The segments break joints and are bolted together through the flanges. The joints are made tight by the use of a tarred rope, together with neat cement.



187. Tile-pipe culverts. The pipes used for this purpose vary from 12" to 24" in diameter. When a larger capacity is required two or more pipes may be laid side by side, but in such a case another design might be preferable. It is frequently specified that "double-strength" or "extra-heavy" pipe shall be used, evidently with the idea that the stresses on a culvert-pipe are greater than on a sewer-pipe. But it has been conclusively demonstrated that, no matter how deep the embankment, the pressure cannot exceed a somewhat uncertain maximum, also that the greatest danger consists in placing the pipe so near the ties that shocks may be directly transferred to the pipe without the cushioning effect of the earth and ballast. When the pipes are well bedded in *clear* earth and there is a sufficient depth of earth over them to avoid direct impact (at least three feet) the ordinary sewer-pipe will be sufficiently strong. "Double-strength" pipe is frequently less perfectly burned, and

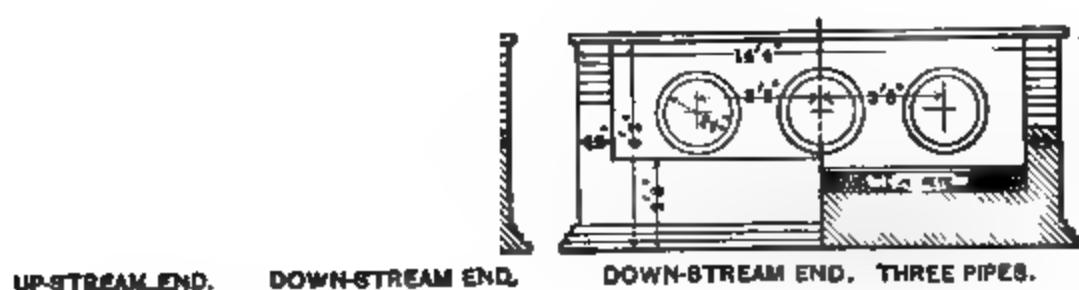


FIG. 98.—STANDARD VITRIFIED-PIPE CULVERT. PLANT SYSTEM. (1891.)

the supposed extra strength is not therefore obtained. In Fig. 98 are shown the standard plans for vitrified-pipe culverts as used on the "Plant system." Tile pipe is much cheaper than iron pipe, but is made in much shorter lengths and requires much more work in laying and especially to obtain a uniform grade.

BOX CULVERTS.

188. Wooden box culverts. This form serves the purpose of a cheap temporary construction which allows the use of a ballasted roadbed. As in all temporary constructions, the area should be made considerably larger than the calculated area (§§ 179–182), not only for safety but also in order that, if the smaller area is demonstrated to be sufficiently large, the permanent construction (probably pipe) may be placed inside without disturbing the embankment. All designs agree in using heavy timbers ($12'' \times 12''$, $10'' \times 12''$, or $8'' \times 12''$) for the side walls, cross-timbers for the roof, every fifth or sixth timber being notched down so as to take up the thrust of the side walls, and planks for the flooring. Fig. 99 shows some of the standard designs as used by the C., M. & St. P. Ry.

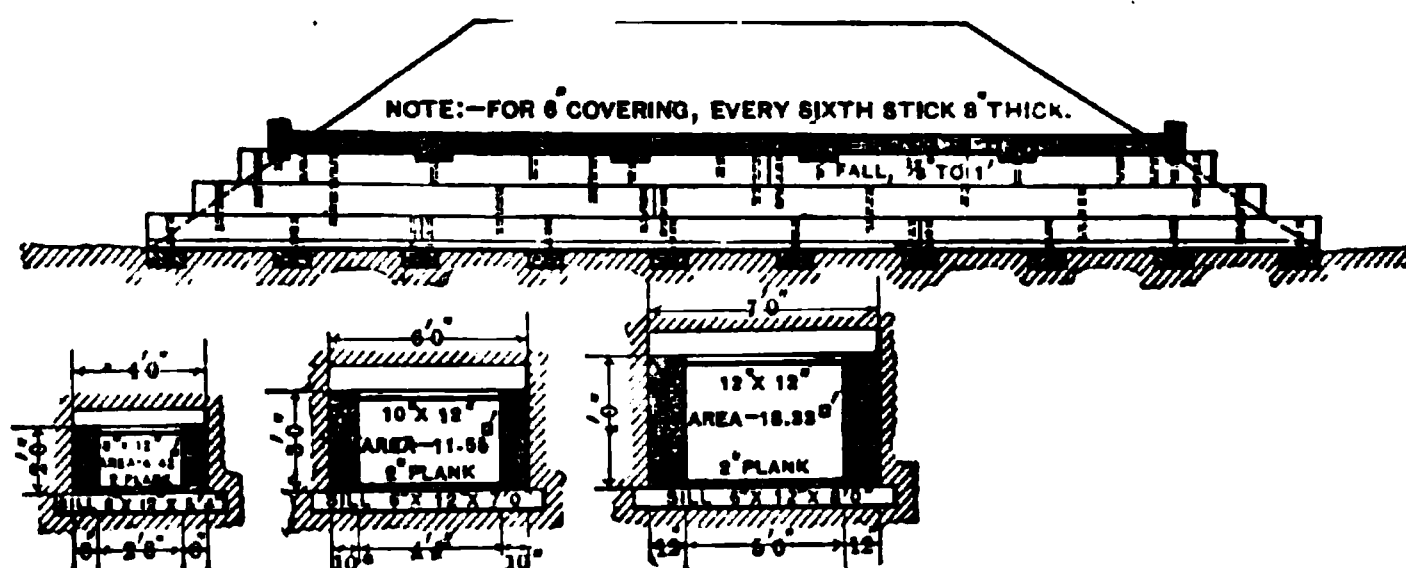


FIG. 99.—STANDARD TIMBER BOX CULVERT. C., M. & ST. P. RY. (Feb. 1889.)

189. Stone box culverts. In localities where a *good* quality of stone is cheap, stone box culverts are the cheapest form of permanent construction for culverts of medium capacity, but their use is decreasing owing to the frequent difficulty in obtaining really suitable stone within a reasonable distance of the culvert. The clear span of the cover-stones varies from 2 to 4 feet. The required thickness of the cover-stones is sometimes calculated by the theory of transverse strains on the basis of certain assumptions of loading—as a function of the height of the embankment and the unit strength of the stone used. Such a method is simply another illustration of a class of calculations

which look very precise and beautiful, but which are worse than useless (because misleading) on account of the hopeless uncertainty as to the true value of certain quantities which must be used in the computations. In the first place the true value of the unit tensile strength of stone is such an uncertain and variable quantity that calculations based on any assumed value for it are of small reliability. In the second place the weight of the prism of earth lying directly above the stone, plus an allowance for live load, is by no means a measure of the load on the stone nor of the forces that tend to fracture it. All earthwork will tend to form an arch above any cavity and thus relieve an uncertain and probably variable proportion of the pressure that might otherwise exist. The higher the embankment the *less* the *proportionate* loading, until at some uncertain height an increase in height will not increase the load on the cover-stones. The effect of frost is likewise large, but uncertain and not computable. The usual practice is therefore to make the thickness such as experience has shown to be safe with a good quality of stone, i.e., about 10 or 12 inches for 2 feet span and up to 16 or 18 inches for 4 feet span. The side walls should be carried down deep enough to prevent their being undermined by scour or heaved by frost. The use of cement mortar is also an important feature of first-class work, especially when there is a rapid scouring current or a liability that the culvert will run under a head. In Fig. 100 are shown standard plans for single and double stone box culverts as used on the Norfolk and Western R.R.

190. Old-rail culverts. It sometimes happens (although very rarely) that it is necessary to bring the grade line within 3 or 4 feet of the bottom of a stream and yet allow an area of 10 or 12 square feet. A single large pipe of sufficient area could not be used in this case. The use of several smaller pipes side by side would be both expensive and inefficient. For similar reasons neither wooden nor stone box culverts could be used. In such cases, as well as in many others where the head-room is not so limited, the plan illustrated in Fig. 101 is a very satisfactory solution of the problem. The old rails, having a length of 8 or

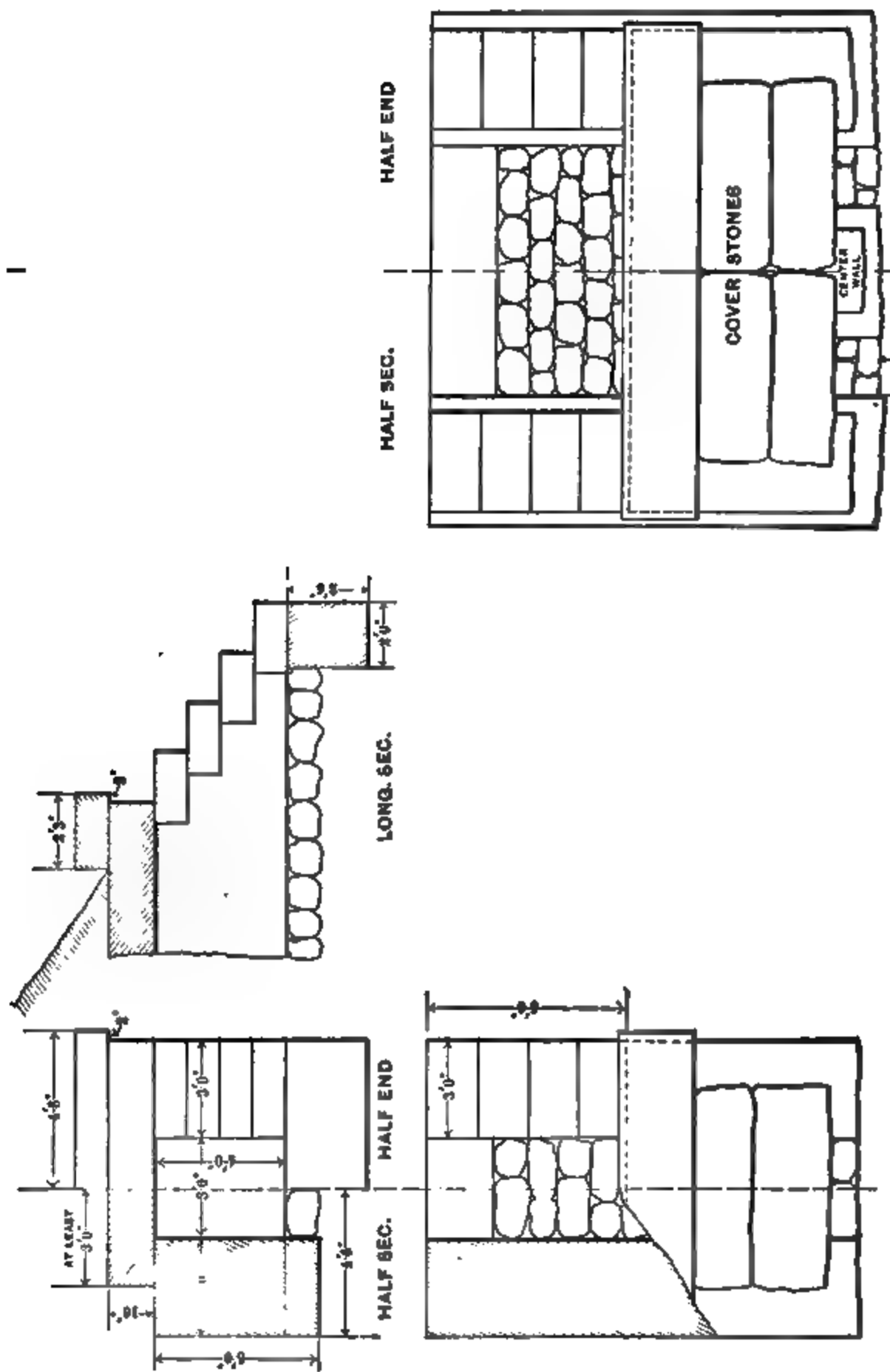


FIG. 100.—STANDARD SINGLE AND DOUBLE STONE CULVERTS (8'X4'). N. & W. R.R. (1890.)

9 feet, are laid close together across a 6-foot opening. Sometimes the rails are held together by long bolts passing through the webs of the rails. In the plan shown the rails are confined

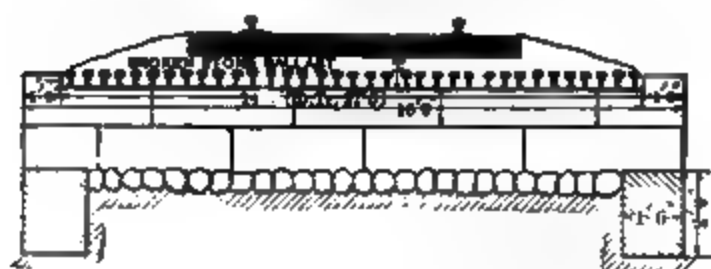


FIG. 101.—STANDARD OLD-RAIL CULVERT. N. & W. R.R. (1895.)

by low end walls on each abutment. This plan requires only 15 inches between the base of the rail and the top of the culvert channel. It also gives a continuous ballasted roadbed.

ARCH CULVERTS.

191. Influence of design on flow. The variations in the design of arch culverts have a very marked influence on the cost and efficiency. To combine the least cost with the greatest efficiency, due weight should be given to the following elements: (*a*) the amount of masonry, (*b*) the simplicity of the constructive work, (*c*) the design of the wing walls, (*d*) the design of the junction of the wing walls with the barrel

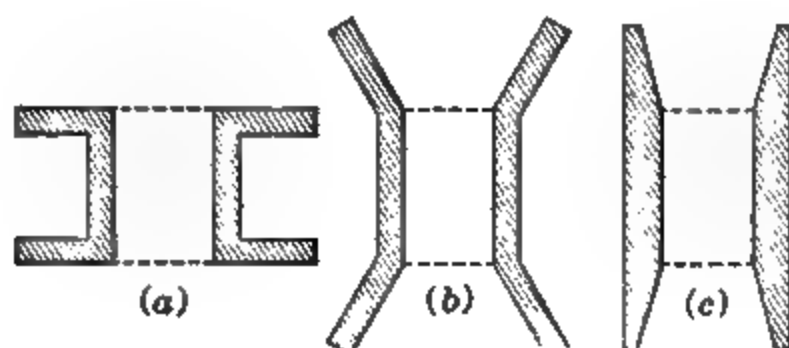


FIG. 102.—TYPES OF CULVERTS.

and faces of the arch, and (*e*) the safety and permanency of the construction. These elements are more or less antagonistic to each other, and the defects of most designs are due to a lack of proper proportion in the design of these opposing interests. The simplest construction (satisfying elements *b* and *e*) is the straight

barrel arch between two parallel vertical head walls, as sketched in Fig. 102, *a*. From a hydraulic standpoint the design is poor, as the water eddies around the corners, causing a great resistance which decreases the flow. Fig. 102, *b*, shows a much better design in many respects, but much depends on the details of the design as indicated in elements (*b*) and (*d*). As a general thing a good hydraulic design requires complicated and expensive masonry construction, i.e., elements (*b*) and (*d*) are opposed. Design 102, *c*, is sometimes inapplicable because the water is liable to work in behind the masonry during floods and perhaps cause scour. This design uses less masonry than (*a*) or (*b*).

192. Example of arch culvert design. In Plate XV is shown the design for an 8-foot arch culvert according to the standard of the Norfolk and Western R.R. Note that the plan uses the flaring wing walls (Fig. 102, *b*) on the up-stream side (thus protecting the abutments from scour) and straight wing walls (similar to Fig. 102, *c*) on the down-stream end. This economizes masonry and also simplifies the constructive work. Note also the simplicity of the junction of the wing walls with the barrel of the arch, there being no re-entrant angles below the springing line of the arch. The design here shown is but one of a set of designs for arches varying in span from 6' to 30'.

MINOR OPENINGS.

193. Cattle-guards. (a) Pit guards. Cattle-guards will be considered under the head of minor openings, since the old-fashioned plan of pit guards, which are even now defended and preferred by some railroad men, requires a break in the continuity of the roadbed. A pit about three feet deep, five feet long, and as wide as the width of the roadbed, is walled up with stone (sometimes with wood), and the rails are supported on heavy timbers laid longitudinally with the rails. The break in the continuity of the roadbed produces a disturbance in the elastic wave running through the rails, the effect of which is noticeable at high velocities. The greatest objection, however, lies in the

PLATE XV.

(To face page 218.)

dangerous consequences of a derailment or a failure of the timbers owing to unobserved decay or destruction by fire—caused perhaps by sparks and cinders from passing locomotives. The very insignificance of the structure often leads to careless in-

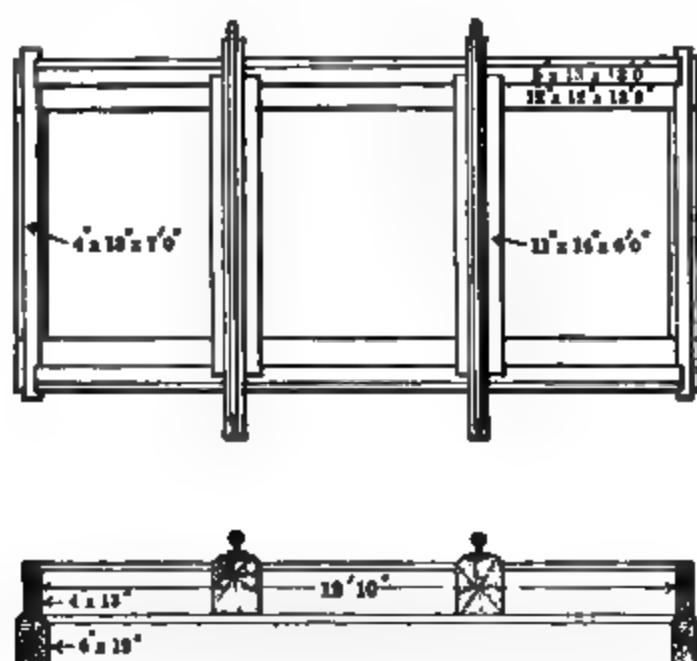


FIG. 103.—PIT CATTLE-GUARDS. P. R. R.

spection. But if a single pair of wheels gets off the rails and drops into the pit, a costly wreck is inevitable. The (once) standard design for such a structure on the Pennsylvania R.R. is shown in Fig. 103.

(b) **Surface cattle-guards.** These are fastened on top of the ties; the continuity of the roadbed is absolutely unbroken and thus is avoided much of the danger of a bad wreck owing to a possible derailment. The device consists essentially of overlaying the ties (both inside and outside the rails) with a surface on which cattle will not walk. The multitudinous designs for such a surface are variously effective in this respect. An objection, which is often urged indiscriminately against all such designs, is the liability that a brake-chain which may happen to be dragging *may* catch in the rough bars which are used. The bars are sometimes "home-made," of wood, as shown in Fig. 104. Iron or steel bars are made as shown in Fig. 105. The general construction is the same as for the wooden bars. The

metal bars have far greater durability, and it is claimed that they are more effective in discouraging cattle from attempting to cross.

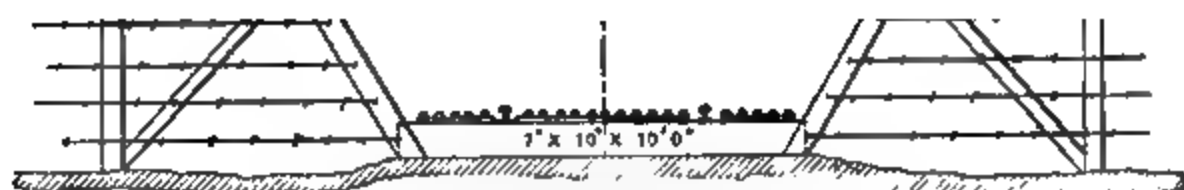


FIG. 104.—CATTLE-GUARD WITH WOODEN SLATS.

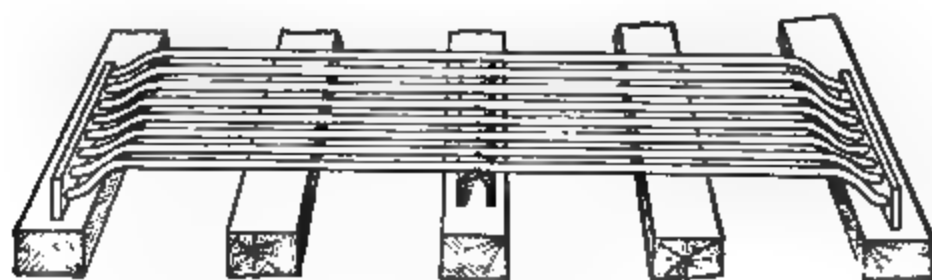
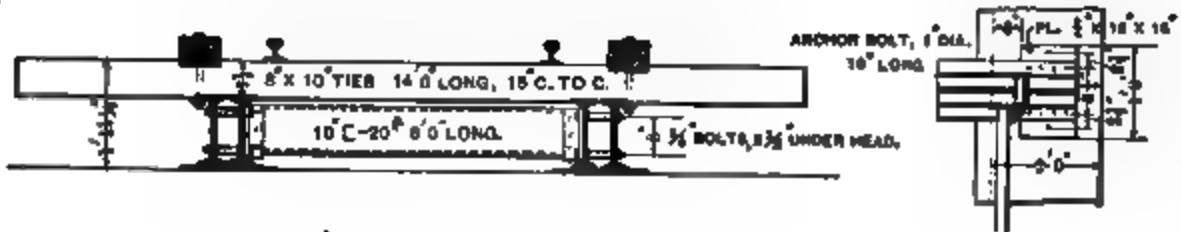


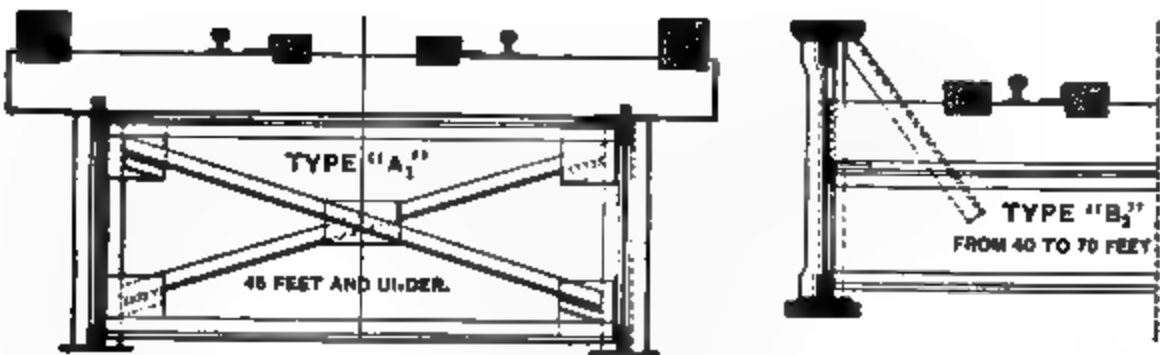
FIG. 105.—MERRILL-STEVENS STEEL CATTLE-GUARD.

194. Cattle-passes. Frequently when a railroad crosses a farm on an embankment, cutting the farm into two parts, the railroad company is obliged to agree to make a passageway through the embankment sufficient for the passage of cattle and perhaps even farm-wagons. If the embankment is high enough so that a stone arch is practicable, the initial cost is the only great objection to such a construction; but if an open wooden structure is necessary, all the objections against the old-fashioned cattle-guards apply with equal force here. The avoidance of a grade crossing which would otherwise be necessary is one of the

PLATE XVI.



STANDARD I-BRIDGES—14-FT. SPAN.
NORFOLK AND WESTERN R.R.
(1891.)



TYPES OF PLATE GIRDER BRIDGES.



C. M. & ST. P. RY.
(Dec. 1895.)

(To face page 219.)

great compensations for the expense of the construction and maintenance of these structures. The construction is sometimes made by placing two pile trestle bents about 6 to 8 feet apart, supporting the rails by stringers in the usual way, the special feature of this construction being that the embankments are filled in behind the trestle bents, and the thrust of the embankments is mutually taken up through the stringers, which are notched at the ends or otherwise constructed so that they may take up such a thrust. The designs for old-rail culverts and arch culverts are also utilized for cattle-passes when suitable and convenient, as well as the designs illustrated in the following section.

195. Standard stringer and I-beam bridges. The advantages of standard designs apply even to the covering of short spans with wooden stringers or with I beams—especially since the methods do not require much vertical space between the rails and the upper side of the clear opening, a feature which is often of prime importance. These designs are chiefly used for culverts or cattle-passes and for crossing *over* highways—providing such a narrow opening would be tolerated. The plans all imply stone abutments, or at least abutments of sufficient stability to withstand all thrust of the embankments. Some of the designs are illustrated in Plate XVI. The preparation of these standard designs should be attacked by the same general methods as already illustrated in § 156. When computing the required transverse strength, due allowance should be made for lateral bracing, which should be amply provided for. Note particularly the methods of bracing illustrated in Plate XVI. The designs calling for iron (or steel) stringers may be classed as permanent constructions, which are cheap, safe, easily inspected and maintained and therefore a desirable method of construction.

CHAPTER VII.

BALLAST.

196. Purpose and requirements. “The object of the ballast is to transfer the applied load over a large surface; to hold the timber work in place horizontally; to carry off the rain-water from the superstructure and to prevent freezing up in winter; to afford means of keeping the ties truly up to the grade line; and to give elasticity to the roadbed.” This extremely condensed statement is a description of an ideally perfect ballast. The value of any given kind of ballast is proportional to the extent to which it fulfills these requirements. The ideally perfect ballast is not necessarily the most economical ballast for all roads. Light traffic generally justifies something cheaper, but a very common error is to use a very cheap ballast when a small additional expenditure would procure a much better ballast which would be much more economical in the long run.

197. Materials. The materials most commonly employed are gravel and broken stone. Burnt clay, cinders, shells, and small coal are occasionally used as ballast when they are especially cheap and convenient or when better kinds are especially expensive. Although it is hardly correct to speak of the natural soil as ballast, yet many miles of cheap railways are “ballasted” with the natural soil, which is then called “mud ballast.”

Mud ballast. When the natural soil is gravelly so that rain will drain through it quickly, it will make a fair roadbed for light traffic, but for heavy traffic, and for the greater part of the length of most roads, the natural soil is a very poor material for ballast; for, no matter how suitable the soil might be along

limited sections of the road, it would practically never happen that the soil would be uniformly good throughout the whole length of the road. Considering that a heavy rain will in one day spoil the results of weeks of patient "surfacing" with mud ballast, it is seldom economical to use "mud" if there is a gravel-bed or other source of ballast anywhere on the line of the road.

Cinders. The advantages consist in the excellent facilities for drainage, ease of handling, and cheapness—after the road is in operation. One disadvantage is excessive dust in dry weather. Cinders are considered preferable to gravel in yards.

Slag. When slag is readily obtainable it furnishes an excellent ballast, free from dust and perfect in drainage qualities. Some kinds of slag are objectionable on account of their deleterious chemical effect on the ties and spikes—especially on metallic ties.

Shells, small coal, etc. These comparatively inferior kinds of ballast are used for light traffic when they are especially cheap and convenient. They are extremely dusty in dry weather, break up into very fine dust, and are but little better than mud.

Gravel. This is the most common form of ballast which may be called good ballast. In 1885, the Roadmasters Association of America voted in favor of gravel ballast as against rock ballast. Although not so stated, this action was perhaps due to a conviction of its real economy for the *average* railroad of this country, which may be called a "light traffic" road. Gravel should preferably be screened over a screen having a $\frac{1}{2}$ " mesh, so as to screen out all dirt and the finest stones. Generally a railroad will be able to find at some point along its line a "gravel-pit" affording a suitable supply. This may be dug out with a steam-shovel, screened if necessary, and sent out over the line by the train-load at a comparatively small cost.

Rock or broken stone. Rock ballast is generally specified to be such as will pass through a $1\frac{1}{2}$ " (or 2") ring. Although preferably broken by hand, machine-broken stone is much cheaper. It is most easily handled with forks. This also has the effect of

screening out the dirt and fine chips which would interfere with effectual drainage. Rock ballast is more expensive in first cost, and also more troublesome to handle, than any other kind, but under heavy traffic will keep in surface better and will require less work for maintenance after the ties have become thoroughly bedded. For roads with very light traffic, running few trains, at comparatively low velocities, the advantages of rock ballast over other kinds are not so pronounced. For such roads rock ballast is an expensive luxury. The amount of traffic which will justify the use of rock ballast will depend on the cost of obtaining ballast of the various kinds.

198. Cross-sections. A depth of 12" under the tie is generally required on the best roads, but for light traffic this is sometimes reduced to 6" and even less. The width is generally 1 to 2 feet less than the width of the roadbed proper—excluding ditches. If the ballast has an average width of 10 feet (12 feet at bottom and 8 feet at top) and an average depth of 15 inches (including that placed between the ties), it will require 2444 cubic yards per mile of track. The P. R.R. estimates 2500 cubic yards of gravel and 2800 cubic yards of stone ballast per mile of single track. On account of the requirements of drainage the best form of cross-section depends on the kind of ballast used.

Mud ballast. Since the great objection to mud ballast lies in its liability to become soft by soaking up the rain that falls, it becomes necessary that it should be drained as quickly and readily as its nature will permit. Fig. 106 shows a typical



FIG. 106.—“ MUD ” BALLAST.

cross-section for mud ballast. It should be crowned 2" above the top of the tie at the center, thence sloped so as to leave a slight clearance under the rail between the ties, thence sloping down to the bottom of the tie at each end and continuing to

slope down to the ditch (in cut), which should be 18'' or 20'' below the bottom of the tie.

Gravel, cinders, slag, etc. The subgrade is crowned 6'' or 8'' in the center, as shown in Fig. 107. The ballast is crowned

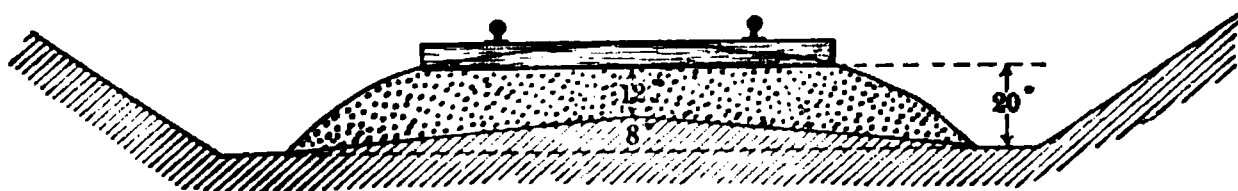


FIG. 107.—GRAVEL BALLAST.

to the top of the tie in the center, but is sloped down to the bottom of the tie at each end. This is necessary (and more especially so with mud ballast) to prevent a possible accumulation and settlement of water at the ends of the tie, which would readily soak into the end fibers and produce decay.

Broken stone. Stone ballast is shouldered out beyond the ends of the ties so as to afford greater lateral binding. The space between the ties is filled up level with the tops. The

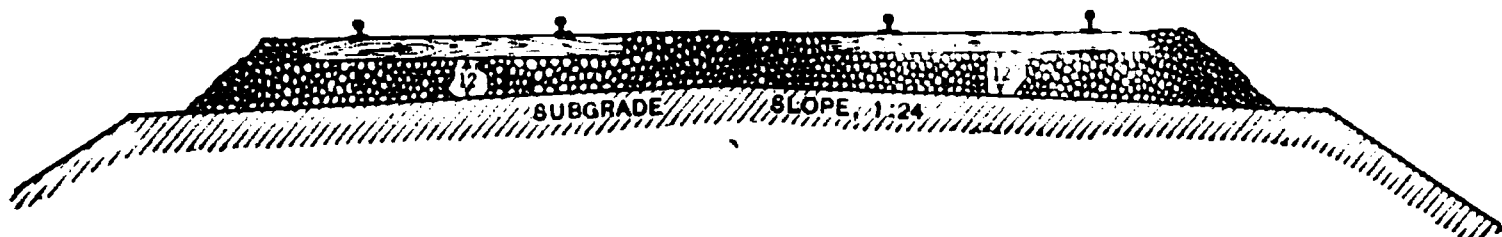


FIG. 108.—BROKEN STONE BALLAST.

perfect drainage of stone ballast permits this to be done without any danger of causing decay of the ties by the accumulation and retention of water.

199. Methods of laying ballast. The cheapest method of laying ballast on new roads is to lay ties and rails directly on the prepared subgrade and run a construction train over the track to distribute the ballast. Then the track is lifted up until sufficient ballast is worked under the ties and the track is properly surfaced. This method, although cheap, is apt to injure the rails by causing bends and kinks, due to the passage of loaded construction trains when the ties are very unevenly and roughly supported, and the method is therefore condemned and prohibited in some specifications. The best method is to draw

in carts (or on a contractor's temporary track) the ballast that is required under the level of the *bottom* of the ties. Spread this ballast carefully to the required surface. Then lay the ties and rails, which will then have a very fair surface and uniform support. A construction train can then be run on the rails and distribute sufficient additional ballast to pack around and between the ties and make the required cross-section.

The necessity for constructing some lines at an absolute minimum of cost and of opening them for traffic as soon as possible has often led to the policy of starting traffic when there is little or no ballast—perhaps nothing more than a mere tamping of the natural soil under the ties. When this is done ballast may subsequently be drawn where required by the train-load on flat cars and unloaded at a minimum of cost by means of a “plough.” The plough has the same width as the cars and is guided either by a ridge along the center of each car or by short posts set up at the sides of the cars. It is drawn from one end of the train to the other by means of a cable. The cable is sometimes operated by means of a small hoisting-engine carried on a car at one end of the train. Sometimes the locomotive is detached temporarily from the train and is run ahead with the cable attached to it.

200. Cost. The cost of ballast *in the track* is quite a variable item for different roads, since it depends (*a*) on the first cost of the material as it comes to the road, (*b*) on the distance from the source of supply to the place where it is used, and (*c*) on the method of handling. The first cost of cinder or slag is frequently insignificant. A gravel-pit may cost nothing except the price of a little additional land beyond the usual limits of the right of way. Broken stone will usually cost \$1 or more per cubic yard. If suitable stone is obtainable on the company's land, the cost of blasting and breaking should be somewhat less than this. The cost of loading the ballast on to trains will be small (per cubic yard) if it is handled with steam-shovels—as in the case of gravel taken from a gravel-pit. Hand-shovelling will cost more. The cost of hauling will depend on the distance

hauled, and also, to a considerable extent, on the limitations on the operation of the train due to the necessity of keeping out of the way of regular trains. There is often a needless waste in this way. The "mud train" is considered a pariah and entitled to no rights whatever, regardless of the large daily cost of such a train and of the necessary gang of men. The cost of broken stone ballast *in the track* is estimated at \$1.25 per cubic yard. The cost of gravel ballast is estimated at 60 c. per cubic yard in the track. The cost of placing and tamping gravel ballast is estimated at 20 c. to 24 c. per cubic yard, for cinders 12 c. to 15 c. per cubic yard. The cost of loading gravel on cars, using a steam-shovel, is estimated at 6 c. to 10 c. per cubic yard.*

* Report Roadmasters Association, 1885.

CHAPTER VIII.

TIES,

AND OTHER FORMS OF RAIL SUPPORT.

201. Various methods of supporting rails. It is necessary that the rails shall be sufficiently supported and braced, so that the gauge shall be kept constant and that the rails shall not be subjected to excessive transverse stress. It is also preferable that the rail support shall be neither rigid (as if on solid rock) nor too yielding, but shall have a *uniform* elasticity throughout. These requirements are more or less fulfilled by the following methods.

(a) **Longitudinals.** Supporting the rails throughout their entire length. This method is very seldom used in this country except occasionally on bridges and in terminals when the longitudinals are supported on cross-ties. In § 224 will be described a system of rails, used to some extent in Europe, having such broad bases that they are self-supporting on the ballast and are only connected by tie-rods to maintain the gauge.

(b) **Cast-iron "bowls" or "pots."** These are castings resembling large inverted bowls or pots, having suitable chairs on top for holding and supporting the rails, and tied together with tie-rods. They will be described more fully later (§ 223).

(b) **Cross-ties of metal or wood.** These will be discussed in the following sections.

202. Economics of ties. The true cost of ties depends on the relative total cost of maintenance for long periods of time. The first cost of the ties delivered to the road is but one item in the

economics of the question. Cheap ties require frequent renewals, which cost for the *labor* of each renewal practically the same whether the tie is of oak or hemlock. Cheap ties make a poor roadbed which will require more track labor to keep even in tolerable condition. The roadbed will require to be disturbed so frequently on account of renewals that the ties never get an opportunity to get settled and to form a smooth roadbed for any length of time. Irregularity in width, thickness, or length of ties is especially detrimental in causing the ballast to act and wear unevenly. The life of ties has thus a more or less direct influence on the life of the rails, on the wear of rolling stock, and on the speed of trains. These last items are not so readily reducible to dollars and cents, but when it can be shown that the total cost, for a long period of time, of several renewals of cheap ties, with all the extra track labor involved, is as great as or greater than that of a few renewals of durable ties, then there is no question as to the real economy. In the following discussions of the merits of untreated ties (either cheap or costly), chemically treated ties, or metal ties, the true question is therefore of the ultimate cost of maintaining any particular kind of ties for an indefinite period, the cost including the first cost of the ties, the labor of placing them and maintaining them to surface, and the somewhat uncertain (but not therefore nonexistent) effect of frequent renewals on repairs of rolling stock, on possible speed, etc.

WOODEN TIES.

203. Choice of wood. This naturally depends, for any particular section of country, on the supply of wood which is most readily available. The woods most commonly used, especially in this country, are oak and pine, oak being the most durable and generally the most expensive. Redwood is used very extensively in California and proves to be extremely durable, so far as decay is concerned, but it is very soft and is much injured by "rail-cutting." This defect is being partly remedied by the

use of tie-plates, as will be explained later. Cedar, chestnut, hemlock, and tamarack are frequently used in this country. In tropical countries very durable ties are frequently obtained from the hard woods peculiar to those countries. According to a recent bulletin of the U. S. Department of Agriculture the proportions of the various kinds used in the United States are about as follows:

Oak.....	60%	Chestnut.....	5%	Cypress.....	2%
Pine.....	20	Hemlock and Tama-		Various.....	1
Cedar.....	6	rack.....	3		
		Redwood.....	3	Total.....	100%

204. Durability. The durability of ties depends on the climate; the drainage of the ballast; the volume, weight, and speed of the traffic; the curvature, if any; the use of tie-plates; the time of year of cutting the timber; the age of the timber and the degree of its seasoning before placing in the track; the nature of the soil in which the timber was grown; and, chiefly, on the species of wood employed. The variability in these items will account for the discrepancies in the reports on the life of various woods used for ties.

White oak is credited with a life of 5 to 12 years, depending principally on the traffic. It is both hard and durable, the hardness enabling it to withstand the cutting tendency of the rail-flanges, and the durability enabling it to resist decay. *Pine* and *redwood* resist decay very well, but are so soft that they are badly cut by the rail-flanges and do not hold the spikes very well, necessitating frequent respiking. Since the spikes must be driven within certain very limited areas on the face of each tie, it does not require many spike-holes to "spike-kill" the tie. On sharp curves, especially with heavy traffic, the wheel-flange pressure produces a side pressure on the rail tending to overturn it, which tendency is resisted by the spike, aided sometimes by rail-braces. Whenever the pressure becomes too great the spike will yield somewhat and will be slightly withdrawn. The resistance is then somewhat less and the spike is soon so loose that it must be redriven in a new hole. If this occurs very

often, the tie may need to be replaced long before any decay has set in. When the traffic is very light, the wood very durable, and the climate favorable ties have been known to last 25 years.

205. Dimensions. The usual dimensions for the best roads (standard gauge) are 8' to 8' 6" long, 6" to 7" thick, and 8" to 10" wide on top and bottom (if they are hewed) or 8" to 9" wide if they are sawed. For cheap roads and light traffic the length is shortened sometimes to 7' and the cross-section also reduced. On the other hand a very few roads use ties 9' long.

Two objections are urged against sawed ties: first, that the grain is torn by the saw, leaving a woolly surface which induces decay; and secondly, that, since timber is not perfectly straight-grained, some of the fibers are cut obliquely, exposing their ends, which are thus liable to decay. The use of a "planer-saw" obviates the first difficulty. Chemical treatment of ties obviates both of these difficulties. Sawed ties are more convenient to handle, are a necessity on bridges and trestles, and it is even claimed, although against commonly received opinion, that actual trial has demonstrated that they are more durable than hewed ties.

206. Spacing. The spacing is usually 14 to 16 ties to a 30-foot rail. This number is sometimes reduced to 12 and even 10, and on the other hand occasionally increased to 18 or 20 by employing narrower ties. There is no economy in reducing the number of ties very much, since for any required stiffness of track it is more economical to increase the number of supports than to increase the weight of the rail. The decreasing cost of rails and the increasing cost of ties have materially changed the relation between number of ties and weight of rail to produce a given stiffness at minimum cost, but many roads have found it economical to employ a large number of ties rather than increase the weight of the rail. On the other hand there is a practical limit to the number that may be employed, on account of the necessary space between the ties that is required for proper tamping. This width is ordinarily about twice the width of the tie. At this rate, with light ties 6" wide and with 12" clear

space, there would be 20 ties per 30-foot rail, or 3520 per mile. The smaller ties can generally be bought much cheaper (proportionately) than the larger sizes, and hence the economy.

Track instructions to foremen generally require that the spacing of ties shall *not* be uniform along the length of any rail. Since the joint is generally the weakest part of the rail structure, the joint requires more support than the center of the rail. Therefore the ties are placed with but 8" or 10" clear space between them at the joints, this applying to 3 or 4 ties at each joint; the remaining ties, required for each rail length, are equally spaced along the remaining distance.

207. Specifications. The specifications for ties are apt to include the items of size, kind of wood, and method of construction, besides other minor directions about time of cutting, seasoning, delivery, quality of timber, etc.

(a) **Size.** The particular size or sizes required will be somewhat as indicated in § 205.

(b) **Kind of wood.** When the kind or kinds of wood are specified, the most suitable kinds that are available in that section of country are usually required.

(c) **Method of construction.** It is generally specified that the ties shall be hewed on two sides; that the two faces thus made shall be parallel planes and that the bark shall be removed. It is sometimes required that the ends shall be sawed off square; that the timber shall be cut in the winter (when the sap is down); and that the ties shall be seasoned for six months. These last specifications are not required or lived up to as much as their importance deserves. It is sometimes required that the ties shall be delivered on the right of way, neatly piled in rows, the alternate rows at right angles, piled if possible on ground not lower than the rails and at least seven feet away from them, the lower row of ties resting on two ties which are themselves supported so as to be clear of the ground.

(d) **Quality of timber.** The usual specifications for sound timber are required, except that they are not so rigid as for a better class of timber work. The ties must be sound, reason-

ably straight-grained, and not very crooked—one test being that a line joining the center of one end with the center of the middle shall not pass outside of the other end. Splits or shakes, especially if severe, should cause rejection.

Specifications sometimes require that the ties shall be cut from single trees, making what is known as “pole ties” and definitely condemning those which are cut or split from larger trunks, giving two “slab ties” or four “quarter ties” for each cross-section, as is illustrated in Fig.



FIG. 109.—METHODS OF CUTTING TIES.

109. Even if pole ties are better, their exclusive use means the rapid destruction of forests of young trees.

208. Regulations for laying and renewing ties. The regulations issued by railroad companies to their track foremen will generally include the following, in addition to directions regarding dimensions, spacing, and specifications given in §§ 204–207. When hewn ties of somewhat variable size are used, as is frequently the case, the largest and best are to be selected for use as joint ties. If the upper surface of a tie is found to be warped (contrary to the usual specifications) so that one or both rails do not get a full bearing across the whole width of the tie, it must be adzed to a true surface along its whole length and not merely notched for a rail-seat. When respiking is necessary and spikes have been pulled out, the holes should be immediately plugged with “wooden spikes,” which are supplied to the foremen for that express purpose, so as to fill up the holes and prevent the decay which would otherwise take place when the hole becomes filled with rain-water. Ties should always be laid at right angles to the rails and never obliquely. Minute regulations to prevent premature rejection and renewal of ties are frequently made. It is generally required that the requisitions for renewals shall be made by the actual count of the individual ties to be renewed instead of by any wholesale estimates. It is unwise to have ties of widely variable size, hardness, or durability adjacent to each

other in the track, for the uniform elasticity, so necessary for smooth riding, will be unobtainable under those circumstances.

209. Cost of ties. When railroads can obtain ties cut by farmers from woodlands in the immediate neighborhood, the price will frequently be as low as 20 c. for the smaller sizes, running up to 50 c. for the larger sizes and better qualities, especially when the timber is not very plentiful. Sometimes if a railroad cannot procure suitable ties from its immediate neighborhood, it will find that adjacent railroads control all adjacent sources of supply for their own use and that ties can only be procured from a considerable distance, with a considerable added cost for transportation. First-class oak ties cost about 75 to 80 c. and frequently much more. Hemlock ties can generally be obtained for 35 c. or less.

PRESERVATIVE PROCESSES FOR WOODEN TIES.

210. General principle. Wood has a fibrous cellular structure, the cells being filled with sap or air. The woody fiber is but little subject to decay unless the sap undergoes fermentation. Preservative processes generally aim at removing as much of the water and sap as possible and filling up the pores of the wood with an antiseptic compound. The most common methods (except one) all agree in this general process and only differ in the method employed to get rid of the sap and in the antiseptic chemical with which the fibers are filled. One valuable feature of these processes lies in the fact that the softer cheaper woods (such as hemlock and pine) are more readily treated than are the harder woods and yet will produce practically as good a tie as a treated hard-wood tie and a very much better tie than an untreated hard-wood tie. The various processes will be briefly described, taking up first the process which is fundamentally different from the others, viz., vulcanizing.

211. Vulcanizing. The process consists in heating the timber to a temperature of 300° to 500° F. in a cylinder, the air being under a pressure of 100 to 175 lbs. per square inch. By this process the albumen in the sap is coagulated, the water evap-

orated, and the pores are partially closed by the coagulation of the albumen. It is claimed that the heat sterilizes the wood and produces chemical changes in the wood which give it an antiseptic character. It has been very extensively used on the elevated lines of New York City, and it is claimed to give perfect satisfaction. The treatment has cost that road 25 c. per tie.

212. Creosoting. This process consists in impregnating the wood with *wood-creosote* or with *dead oil of coal-tar*. *Wood-creosote* is one of the products of the destructive distillation of wood—usually long-leaf pine. *Dead oil of coal-tar* is a product of the distillation of coal-tar at a temperature between 480° and 760° F. It would require about 35 to 50 pounds of creosote to completely fill the pores of a cubic foot of wood. But it would be impossible to force such an amount into the wood, nor is it necessary or desirable. About 10 pounds per cubic foot, or about 35 pounds per tie, is all that is necessary. For piling placed in salt water about 18 to 20 pounds per cubic foot is used, and the timber is then perfectly protected against the ravages of the *teredo navalis*. To do the work, long cylinders, which may be opened at the ends, are necessary. Usually the timbers are run in and out on iron carriages running on rails fastened to braces on the inside of the cylinder. When the load has been run in, the ends of the cylinder are fastened on. The water and air in the pores of the wood are first drawn out by subjecting the wood alternately to steam-pressure and to the action of a vacuum-pump. This is continued for several hours. Then, after one of the vacuum periods, the cylinder is filled with creosote oil at a temperature of about 170° F. The pumps are kept at work until the pressure is about 80 to 100 pounds per square inch, and is maintained at this pressure from one to two hours according to the size of the timber. The oil is then withdrawn, the cylinders opened, the train pulled out and another load made up in 40 to 60 minutes. The average time required for treating a load is about 18 or 20 hours, the absorption about 10 or 11 pounds of oil per cubic foot, and the cost (1894) from \$12.50 to \$14.50 per thousand feet B. M.

213. Burnettizing (chloride-of-zinc process). This process is very similar to the creosoting process except that the chemical is chloride of zinc, and that the chemical is not heated before use. The preliminary treatment of the wood to alternate vacuum and pressure is not continued for quite so long a period as in the creosoting process. Care must be taken, in using this process, that the ties are of as uniform quality as possible, for seasoned ties will absorb much more zinc chloride than unseasoned (in the same time), and the product will lack uniformity unless the seasoning is uniform. The A., T. & S. Fé R.R. has works of its own at which ties are treated by this process at a cost of about 25 c. per tie. The Southern Pacific R.R. also has works for burnettizing ties at a cost of 9.5 to 12 c. per tie. The zinc-chloride solution used in these works contains only 1.7% of zinc chloride instead of over 3% as used in the Santa Fé works, which perhaps accounts partially for the great difference in cost per tie. One great objection to burnettized ties is the fact that the chemical is somewhat easily washed out, when the wood again becomes subject to decay. Another objection, which is more forcible with respect to timber subject to great stresses, as in trestles, than to ties, is the fact that when the solution of zinc chloride is made strong (over 3%) the timber is made very brittle and its strength is reduced. The reduction in strength has been shown by tests to amount to $\frac{1}{4}$ to $\frac{1}{10}$ of the ultimate strength, and that the elastic limit has been reduced by about $\frac{1}{4}$.

214. Kyanizing (bichloride-of-mercury or corrosive-sublimate process). This is a process of "steeping." It requires a much longer time than the previously described processes, but does not require such an expensive plant. Wooden tanks of sufficient size for the timber are all that is necessary. The corrosive sublimate is first made into a concentrated solution of one part of chemical to six parts of *hot* water. When used in the tanks this solution is weakened to 1 part in 100 or 150. The wood will absorb about 5 to 6.5 pounds of the bichloride per 100 cubic feet, or about one pound for each 4 to 6 ties. The timber is allowed to soak in the tanks for several days, the general rule

being about one day for each inch of least thickness and one day over—which means seven days for six-inch ties, or thirteen (to fifteen) days for 12" timber (least dimension). The process is somewhat objectionable on account of the chemical being such a virulent poison, workmen sometimes being sickened by the fumes arising from the tanks. On the Baden railway (Germany) kyanized ties last 20 to 30 years. On this railway the wood is always air-dried for two weeks after impregnation and before being used, which is thought to have an important effect on its durability. The solubility of the chemical and the liability of the chemical washing out and leaving the wood unprotected is an element of weakness in the method.

215. Wellhouse (or zinc-tannin) process. The last two methods described (as well as some others employing similar chemicals) are open to the objection that since the wood is impregnated with an aqueous solution, it is liable to be washed out very rapidly if the wood is placed under water, and will even disappear, although more slowly, under the action of moisture and rain. Several processes have been proposed or patented to prevent this. Many of them belong to one class, of which the Wellhouse process is a sample. By these processes the timber is successively subjected to the action of two chemicals, each individually soluble in water, and hence readily impregnating the timber, but the chemicals when brought in contact form insoluble compounds which cannot be washed out of the wood-cells. By the Wellhouse process, the wood is first impregnated with a solution of chloride of zinc and glue, and is then subjected to a bath of tannin under pressure. The glue and tannin combine to form an insoluble leathery compound in the cells, which will prevent the zinc chloride from being washed out. It is being used by the A., T. & S. Fé R.R., their works being located at Las Vegas, New Mexico, and also by the Union Pacific R.R. at their works at Laramie, Wyo. In 1897 Mr. J. M. Meade, a resident engineer on the A., T. & S. Fé, exhibited to the Roadmasters Association of America a piece of a tie treated by this process which had been taken from the tracks after

nearly 13 years' service. The tie was selected at random, was taken out for the sole purpose of having a specimen, and was still in sound condition and capable of serving many years longer. The cost of the treatment was then quoted as 13 c. per tie. It was claimed that the treatment trebled the life of the tie besides adding to its spike-holding power.

216. Cost of treating. The cost of treating ties by the various methods has been estimated as follows*—assuming that the plant was of sufficient capacity to do the work economically: creosoting, 25 c. per tie; vulcanizing, 25 c. per tie; burnettizing (chloride of zinc), 8.25 c. per tie; kyanizing (steeping in corrosive sublimate), 14.6 c. per tie; Wellhouse process (chloride of zinc and tannin), 11.25 c. per tie. These estimates are only for the net cost at the works and do not include the cost of hauling the ties to and from the works, which may mean 5 to 10 c. per tie. Some of these processes have been installed on cars which are transported over the road and operated where most convenient.

217. Economics of treated ties. The fact that treated ties are not universally adopted is due to the argument that the added life of the tie is not worth the extra cost. If ties can be bought for 25 c., and cost 25 c. for treatment, and the treatment only doubles their life, there is apparently but little gained except the work of placing the extra tie in the track, which is more or less offset by the interest on 25 c. for the life of the untreated tie, and the larger initial outlay makes a stronger impression on the mind than the computed ultimate economy. But when ties cost 75 c. and treatment costs only 25 c., or perhaps less, then the economy is more apparent and unquestionable. But this analysis may be made more closely. As shown in § 202, the disturbance of the roadbed on account of frequent renewals of untreated ties is a disadvantage which would justify an appreciable expenditure to avoid, although it is

* Bull. No. 9, U. S. Dept. of Agric., Div. of Forestry. App. No. 1, by Henry Flad.

very difficult to closely estimate its true value. The annual cost of a system of ties may be considered as the sum of (*a*) the interest on the first cost, (*b*) the annual sinking fund that would buy a new tie at the end of its life, and (*c*) the average annual cost of maintenance for the life of the tie, which includes the cost of laying and the considerable amount of subsequent tamping that must be done until the tie is fairly settled in the roadbed, beside the regular trackwork on the tie, which is practically constant. This last item is difficult to compute, but it is easy to see that, since the cost of laying the tie and the subsequent tamping to obtain proper settlement is the same for all ties (of similar form), the *average* annual charge on the longer-lived tie would be much less. In the following comparison item (*c*) is disregarded, simply remembering that the advantage is with the longer-lived tie.

	Untreated tie.	Treated tie.
Original cost	40 cents	65 cents
Life (assumed at)	7 years	14 years
Item (<i>a</i>)—interest on first cost @ 4%	1.6 cents	2.6 cents
“ (<i>b</i>)—sinking fund @ 4%	5.1 “	3.6 “
“ (<i>c</i>)—(considered here as offsetted)	—	—
Average annual cost (except item (<i>c</i>))	6.7 cents	6.2 cents

On this basis treated ties will cost 0.5 cent *less* per annum *besides* the advantage of item (*c*) and the still more indefinite advantages resulting from smoother running of trains, less wear and tear on rolling stock, etc., due to less disturbance of the roadbed.

In Europe, where wood is expensive, untreated ties are seldom used, as the treatment is always considered to be worth more than it costs. The rapid destruction of the forests of timber in this country is having the effect of increasing the price, so that it will not be long before treated ties (or metal ties) will be economical for a large majority of the railroads of the country.

METAL TIES.

218. Extent of use. In 1894 * there were nearly 35000 miles of "metal track" in various parts of the world. Of this total, there were 3645 miles of "longitudinals" (see § 224), found exclusively in Europe, nearly all of it being in Germany. There were over 12000 miles of "bowls and plates" (see § 223), found almost entirely in British India and in the Argentine Republic. The remainder, over 18000 miles, was laid with metal cross-ties of various designs. There were over 8000 miles of metal cross-ties in Germany alone, about 1500 miles in the rest of Europe, over 6000 miles in British India, nearly 1000 miles in the rest of Asia, and about 1500 miles more in various other parts of the world. Several railroads in this country have tried various designs of these ties, but their use has never passed the experimental stage. These 35000 miles represent about 9% of the total railroad mileage of the world—nearly 400000 miles. They represent about 17.6% of the total railroad mileage, exclusive of the United States and Canada, where they are not used at all, except experimentally. In the four years from 1890 to 1894 the use of metal track increased from less than 25000 miles to nearly 35000 miles. This increase was practically equal to the total increase in railroad mileage during that time, exclusive of the increase in the United States and Canada. This indicates a large growth in the percentage of metal track to total mileage, and therefore an increased appreciation of the advantages to be derived from their use.

219. Durability. The durability of metal track is still far from being a settled question, due largely to the fact that the best form for such track is not yet determined, and that a large part of the apparent failures in metal track have been evidently due to defective design. Those in favor of them estimate the life as from 30 to 50 years. The opponents place it as not more than 20 years, or perhaps as long as the best of wooden ties.

* Bulletin No. 9, U. S. Dept. of Agriculture, Div. of Forestry.

Unlike the wooden tie, however, which deteriorates as much with time as with usage, the life of a metal tie is more largely a function of the traffic. The life of a well-designed metal tie has been estimated at 150000 to 200000 trains; for 20 trains per day, or say 6000 per year, this would mean from 25 to 33 years. 20 trains per day on a *single* track is a much larger number than will be found on the majority of railroads. Metal ties are found to be subject to rust, especially when in damp localities, such as tunnels; but on the other hand it is in such confined localities, where renewals are troublesome, that it is especially desirable to employ the best and longest-lived ties. Paint, tar, etc., have been tried as a protection against rust, but the efficacy of such protection is as yet uncertain, the conditions preventing any renewal of the protection—such as may be done by repainting a bridge, for example. Failures in metal cross-ties have been largely due to cracks which begin at a corner of one of the *square* holes which are generally *punched* through the tie, the holes being made for the bolts by which the rails are fastened to the tie. The holes are generally *punched* because it is cheaper. Reaming the holes after punching is thought to be a safeguard against this frequent cause of failure. Another method is to round the corners of the square punch with a radius of about $\frac{1}{8}$ ". If a crack has already started, the spread of the crack may be prevented by drilling a small hole at the end of it.

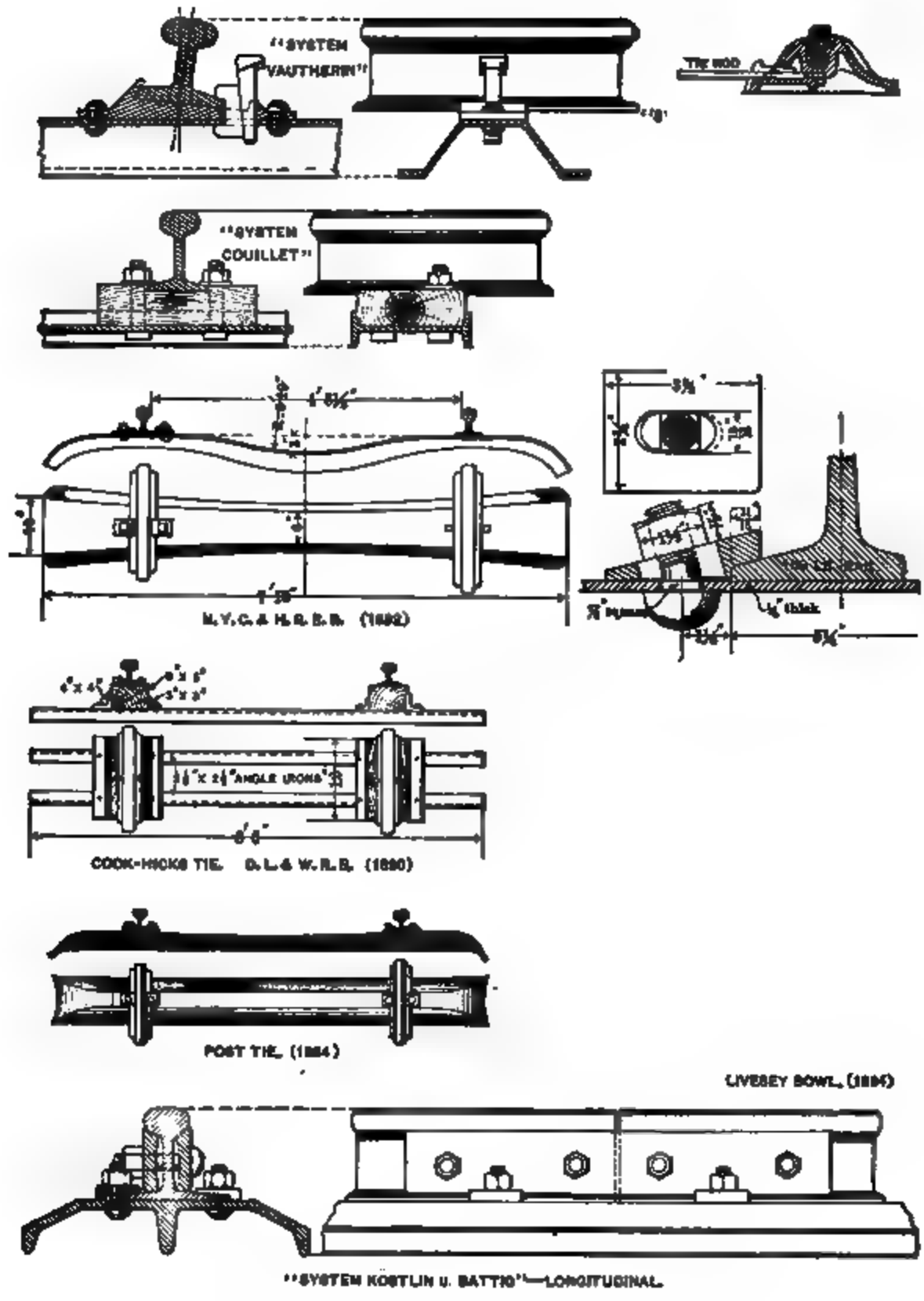
220. Form and dimensions of metal cross-ties. Since stability in the ballast is an essential quality for a tie, this must be accomplished either by turning down the end of the tie or by having some form of lug extending downward from one or more points of the tie. The ties are sometimes depressed in the center (see Plate XVII, N. Y. C. & H. R. R.R. tie) to allow for a thick covering of ballast on top in order to increase its stability in the ballast. This form requires that the ties should be sufficiently well tamped to prevent a tendency to bend out straight, thus widening the gauge. Many designs of ties are objectionable because they cannot be placed in the track without disturbing adjacent ties. The failure of many metal cross-

ties, otherwise of good design, may be ascribed to too light weight. Those weighing much less than 100 pounds have proved too light. From 100 to 130 pounds weight is being used satisfactorily on German railroads. The general outside dimensions are about the same as for wooden ties, except as to thickness. The metal is generally from $\frac{1}{4}$ " to $\frac{3}{8}$ " thick. They are, of course, only made of wrought iron or steel, cast iron being used only for "bowls" or "plates" (see § 213). The details of construction of some of the most commonly used ties may be seen by a study of Plate XVII.

221. Fastenings. The devices for fastening the rails to the ties should be such that the gauge may be widened if desired on curves, also that the gauge can be made true regardless of slight inaccuracies in the manufacture of the ties, and also that shims may be placed under the rail if necessary during cold weather when the tie is frozen into the ballast and cannot be easily disturbed. Some methods of fastening require that the base of the rail be placed against a lug which is riveted to the tie or which forms a part of it. This has the advantage of reducing the number of pieces, but is apt to have one or more of the disadvantages named above. Metal keys or wooden wedges are sometimes used, but the majority of designs employ some form of bolted clamp. The form adopted for the experimental ties used by the N. Y. C. & H. R. R.R. (see Plate XVII) is especially ingenious in the method used to vary the gauge or allow for inaccuracies of manufacture. Plate XVII shows some of the methods of fastening adopted on the principal types of ties.

222. Cost. The cost of metal cross-ties in Germany averages about 1.6 c. per pound or about \$1.60 for a 100-lb. tie. The ties manufactured for the N. Y. C. & H. R. R.R. in 1892 weighed about 100 lbs. and cost \$2.50 per tie, but if they had been made in larger quantities and with the present price of steel the cost would possibly have been much lower. The item of freight from the place of manufacture to the place where used is no inconsiderable item of cost with some roads. Metal cross-ties have been used by some street railroads in this country.

PLATE XVII.



METAL TIES.

(To face page 240)

Those used on the Terre Haute Street Railway weigh 60 pounds and cost about 66 c. for the tie, or 74 c. per tie with the fastenings.

223. Bowls or plates. As mentioned before, over 12000 miles of railway, chiefly in British India and in the Argentine Republic, are laid with this form of track. It consists essentially of large cast-iron inverted "bowls" laid at intervals under each rail and opposite each other, the opposite bowls being tied together with tie-rods. A suitable chair is riveted or bolted on to the top of each bowl so as to properly hold the rail. Being made of cast iron, they are not so subject to corrosion as steel or wrought iron. They have the advantage that when old and worn out their scrap value is from 60 to 80% of their initial cost, while the scrap value of a steel or wrought-iron tie is practically nothing. Failure generally occurs from breakage, the failures from this cause in India being about 0.4 per cent per annum. They weigh about 250 lbs. apiece and are therefore quite expensive in first cost and transportation charges. There are miles of them in India which have already lasted 25 years and are still in a serviceable condition. Some illustrations of this form of tie are shown in Plate XVII.

224. Longitudinals.* This form, the use of which is confined almost exclusively to Germany, is being gradually replaced on many lines by metal cross-ties. The system generally consists of a compound rail of several parts, the upper bearing rail being very light and supported throughout its length by other rails, which are suitably tied together with tie-rods so as to maintain the proper gauge, and which have a sufficiently broad

* Although the discussion of longitudinals might be considered to belong more properly to the subject of RAILS, yet the essential idea of all designs must necessarily be the *support* of a rail-head on which the rolling stock may run, and therefore this form, unused in this country, will be briefly described here.

base to be properly supported in the ballast. One great objection to this method of construction is the difficulty of obtaining proper drainage especially on grades, the drainage having a tendency to follow along the lines of the rails.

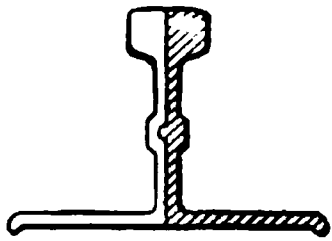


FIG. 110. The construction is much more complicated on sharp curves and at frogs and switches. Another fundamentally different form of longitudinal is the Haarman compound "self-bearing" rail, having a base 12" wide and a height of 8", the alternate sections breaking joints so as to form a practically continuous rail.

Some of the other forms of longitudinals are illustrated in Plate XVII.

For a very complete discussion of the subject of metal ties, see the "Report on the Substitution of Metal for Wood in Railroad Ties" by E. E. Russell Tratman, it being Bulletin No. 4, Forestry Division of the U. S. Dept. of Agriculture.

CHAPTER IX.

RAILS.

225. Early forms. The first rails ever laid were wooden stringers which were used on very short tram-roads around coal-mines. As the necessity for a more durable rail increased, owing chiefly to the invention of the locomotive as a motive power, there were invented successively the cast-iron “fish-belly” rail and various forms of wrought-iron strap rails which finally developed into the T rail used in this country and the double-headed rail, supported by chairs, used so extensively in England. The cast-iron rails were cast in lengths of about 3 feet and were supported in iron chairs which were sometimes set upon stone piers. A great deal of the first railroad track of this country was laid with longitudinal stringers of wood placed upon cross-ties, the inner edge of the stringers being

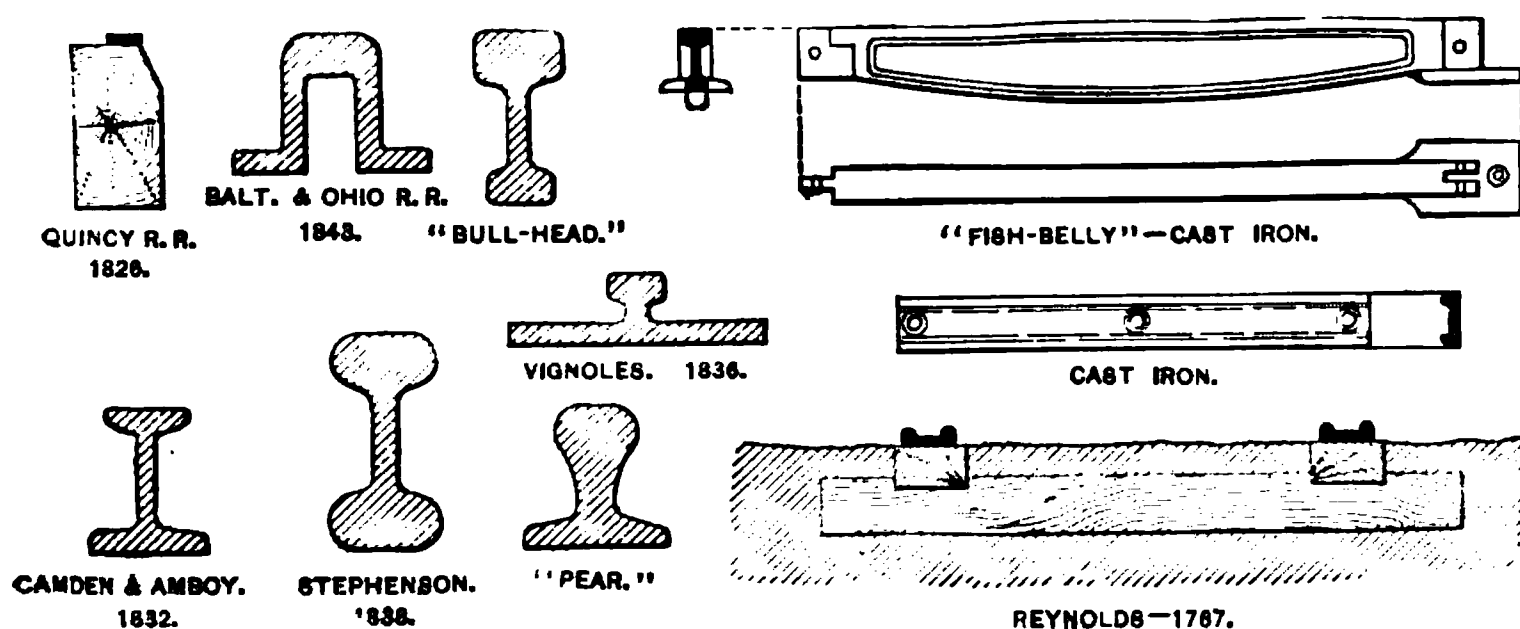


FIG. 111.—EARLY FORMS OF RAILS.

protected by wrought-iron straps. The “bridge” rails were first rolled in this country in 1844. The “pear” section was

an approach to the present form, but was very defective on account of the difficulty of designing a good form of joint. The "Stevens" section was designed in 1830 by Col. Robert L. Stevens, Chief Engineer of the Camden and Amboy Railroad; although quite defective in its proportions, according to the present knowledge of the requirements, it is essentially the present form. In 1836, Charles Vignoles invented essentially the same form in England; this form is therefore known throughout England and Europe as the Vignoles rail.

226. Present standard forms. The larger part of modern railroad track is laid with rails which are either "T" rails or the double-headed or "bull-headed" rails which are carried in chairs. The double-headed rail was designed with a symmetrical form with the idea that after one head had been worn out by traffic the rail could be reversed, and that its life would be practically doubled. Experience has shown that the wear of the rail in the chairs is very great; so much so that when one head has been worn out by traffic the whole rail is generally useless. If the rail is turned over, the worn places, caused by the chairs, make a rough track and the rail appears to be more brittle and subject to fracture, possibly due to the crystallization that may have occurred during the previous usage and to the reversal of stresses in the fibers. Whatever the explanation, experience has demonstrated the *fact*. The "bull-headed" rail has the lower

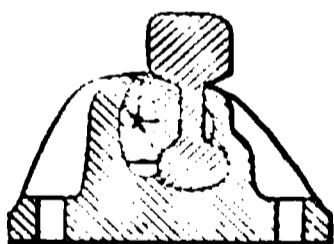


FIG. 112.—BULL-HEADED RAIL AND CHAIR. head only large enough to properly hold the wooden keys with which the rail is secured to the chairs (see Fig. 112) and furnish the necessary strength. The use of these rails requires the use of two cast-iron chairs for each tie. It is claimed that such track is better for heavy and fast traffic, but it is more expensive to build and maintain. It is the standard form of track in England and some parts of Europe.

Until a few years ago there was a very great multiplicity in the designs of "T" rails as used in this country, nearly every prominent railroad having its own special design, which

perhaps differed from that of some other road by only a very minute and insignificant detail, but which nevertheless would require a complete new set of rolls for rolling. This certainly must have had a very appreciable effect on the cost of rails. In 1893, the American Society of Civil Engineers, after a very exhaustive investigation of the subject, extending over several years, having obtained the opinions of the best experts of the country, adopted a series of sections which have been very extensively adopted by the railroads of this country. Instead of having the rail sections for various weights to be geometrically similar figures, certain dimensions are made constant, regardless of the weight. It was decided that the metal should be distributed through the section in the proportions of—head 42%, web 21%, and flange 37%. The top of the head should have a radius of 12''; the top corner radius of head should be $\frac{5}{16}$ ''; the

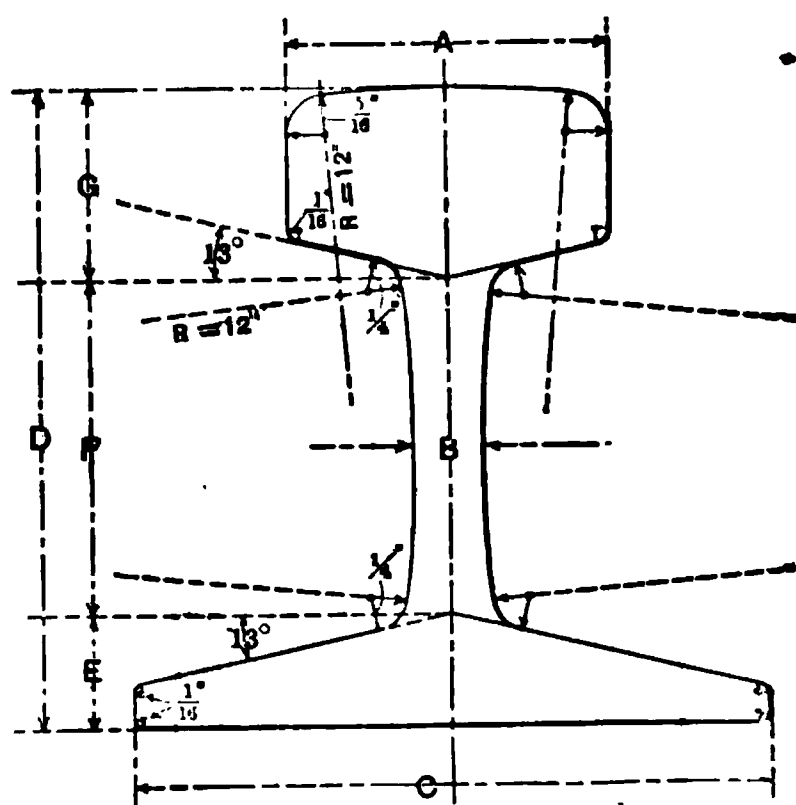


FIG. 113.—AM. SOC. C. E. STANDARD RAIL SECTION.

lower corner radius of head should be $\frac{1}{16}$ ''; the corners of the flanges, $\frac{1}{16}$ '' radius; side radius of web, 12''; top and bottom radii of web corners, $\frac{1}{4}$ ''; and angles with the horizontal of the under side of the head and the top of the flange, 13°. The sides of the head are vertical.

The height of the rail (D) and the width of the base (C) are always made equal to each other.

	Weight per Yard.												
	40	45	50	55	60	65	70	75	80	85	90	95	100
A	1½"	2"	2½"	3½"	4½"	5½"	6½"	7½"	8½"	9½"	10½"	11½"	12½"
B	¾"	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"	6½"
C & D	¾"	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"	6½"
E	¾"	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"	6½"
F	1½"	2"	2½"	3½"	4½"	5½"	6½"	7½"	8½"	9½"	10½"	11½"	12½"
G	1½"	2"	2½"	3½"	4½"	5½"	6½"	7½"	8½"	9½"	10½"	11½"	12½"

The chief features of disagreement among railroad men relate to the radius of the upper corner of the head and the slope of the side of the head. The radius ($\frac{5}{8}$ "') adopted for the upper corner (constant for all weights) is a little more than is advocated by those in favor of "sharp corners" who often use a radius of $\frac{1}{4}$ ". On the other hand it is much less than is advocated by those who consider that it should be nearly equal to (or even greater than) the larger radius universally adopted for the corner of the wheel-flange. The discussion turns on the relative rapidity of rail wear and the wear of the wheel-flanges as affected by the relation of the form of the wheel-tread to that of the rail. It is argued that sharp rail corners wear the wheel-flanges so as to produce sharp flanges, which are liable to cause derailment at switches and also to require that the tires of engine-drivers must be more frequently turned down to their true form. On the

FIG. 114. — RELATION OF RAIL TO WHEEL-TREAD.

other hand it is generally believed that rail wear is much less rapid while the area of contact between the rail and wheel-flange is small, and that when the rail has worn down, as it invariably does, to nearly the same form as the wheel-flange, the rail wears away very quickly.

227. Weight for various kinds of traffic. The heaviest rails in regular use weigh 100 lbs. per yard, and even these are only used on some of the heaviest traffic sections of such roads as the N. Y. Central, the Pennsylvania, the N. Y., N. H. & H., and

a few others. Probably the larger part of the mileage of the country is laid with 60- to 75-lb. rails—considering the fact that “the larger part of the mileage” consists of comparatively light-traffic roads and may exclude all the heavy trunk lines. Very light-traffic roads are sometimes laid with 56-lb. rails. Roads with fairly heavy traffic generally use 75- to 85-lb. rails, especially when grades are heavy and there is much and sharp curvature. The tendency on all roads is toward an increase in the weight, rendered necessary on account of the increase in the weight and capacity of rolling stock, and due also to the fact that the price of rails has been so reduced that it is both better and cheaper to obtain a more solid and durable track by increasing the weight of the rail rather than by attempting to support a weak rail by an excessive number of ties or by excessive track labor in tamping. It should be remembered that in buying rails the mere weight is, in one sense, of no importance. The important thing to consider is the **STRENGTH** and the **STIFFNESS**. If we assume that all weights of rails have *similar* cross-sections (which is nearly although not exactly true), then, since for beams of similar cross-sections the *strength* varies as the *cube* of the homologous dimensions and the *stiffness* as the *fourth power*, while the area (and therefore the weight per unit of length) only varies as the *square*, it follows that the stiffness varies as the square of the weight, and the strength as the $\frac{2}{3}$ power of the weight. Since for ordinary variations of weight the price per ton is the same, adding (say) 10% to the weight (and cost) adds 21% to the stiffness and over 15% to the strength. As another illustration, using an 80-lb. rail instead of a 75-lb. rail adds only 6 $\frac{2}{3}$ % to the cost, but adds about 14% to the stiffness and nearly 11% to the strength. This shows why heavier rails are more economical and are being adopted even when they are not absolutely needed on account of heavier rolling stock. The stiffness, strength, and consequent durability are increased in a much greater ratio than the cost.

228. Effect of stiffness on traction. A very important but generally unconsidered feature of a stiff rail is its effect on trac-

tive force. An extreme illustration of this principle is seen when a vehicle is drawn over a soft sandy road. The constant compression of the sand in front of the wheel has virtually the same effect on traction as drawing the wheel up a grade whose steepness depends on the radius of the wheel and the depth of the rut. On the other hand, if a wheel, made of perfectly elastic material, is rolled over a surface which, while supported with absolute rigidity, is also perfectly elastic, there would be a forward component, caused by the expanding of the compressed metal just behind the center of contact, which would just balance the backward component. If the rail was supported throughout its length by an absolutely rigid support, the high elasticity of the wheel-tires and rails would reduce this form of resistance to an insignificant quantity, but the ballast and even the ties are comparatively inelastic. When a weak rail yields, the ballast is more or less compressed or displaced, and even though the elasticity of the rail brings it back to nearly its former place, the work done in compressing an inelastic material is wholly lost. The effect of this on the fuel account is certainly very considerable and yet is frequently entirely overlooked. It is practically impossible to compute the saving in tractive power, and therefore in cost of fuel, resulting from a given increase in the weight and stiffness of the rail, since the yielding of the rail is so dependent on the spacing of the ties, the tamping, etc. But it is not difficult to perceive in a general way that such an economy is possible and that it should not be neglected in considering the value of stiffness in rails.

229. Length of rails. The standard length of rails with most railroads is 30 feet. In recent years many roads have been trying 45-foot and even 60-foot rails. The argument in favor of longer rails is chiefly that of the reduction in track-joints, which are costly to construct and to maintain and are a fruitful source of accidents. Mr. Morrison of the Lehigh Valley R.R.* declares that, as a result of extensive experience with 45-foot rails

on that road, he finds that they are much less expensive to handle, and that, being so long, they can be laid around sharp curves without being curved in a machine, as is necessary with the shorter rails. The great objection to longer rails lies in the difficulty in allowing for the expansion, which will require, in the coldest weather, an opening at the joint of nearly $\frac{3}{4}$ " for a 60-foot rail. The Pennsylvania R.R. and the Norfolk and Western R.R. each have a considerable mileage laid with 60-foot rails.

230. Expansion of rails. Steel expands at the rate of .0000065 of its length per degree Fahrenheit. The extreme range of temperature to which any rail will be subjected will be about 160° , or say from -20° F. to $+140^{\circ}$ F. With the above coefficient and a rail length of 60 feet the expansion would be 0.0624 foot, or about $\frac{3}{4}$ inch. But it is doubtful whether there would ever be such a range of motion even if there were such a range of temperature. Mr. A. Torrey, chief engineer of the Mich. Cent. R.R., experimented with a section over 500 feet long, which, although not a single rail, was made "continuous" by rigid splicing, and he found that there was no appreciable additional contraction of the rail at any temperature below $+20$ F. The reason is not clear, but the *fact* is undeniable.

The heavy girder rails, used by the street railroads of the country, are bonded together with perfectly tight rigid joints which do not permit expansion. If the rails are laid at a temperature of 60° F. and the temperature sinks to 0° , the rails have a *tendency* to contract .00039 of their length. If this tendency is resisted by the friction of the pavement in which the rails are buried, it only results in a tension amounting to .00039 of the modulus of elasticity, or say 10920 pounds per square inch, assuming 28 000 000 as the modulus of elasticity. This stress is not dangerous and may be permitted. If the temperature rises to 120° F., a tendency to expansion and buckling will take place, which will be resisted as before by the pavement, and a compression of 10920 pounds per square inch will be induced, which will likewise be harmless. The range of tempera-

ture of rails which are buried in pavement is much less than when they are entirely above the ground and will probably never reach the above extremes. Rails supported on ties which are only held in place by ballast must be allowed to expand and contract almost freely, as the ballast cannot be depended on to resist the distortion induced by any considerable range of temperature, especially on curves.

231. Rules for allowing for temperature. Track regulations generally require that the track foremen shall use iron (*not* wooden) shims for placing between the ends of the rails while splicing them. The thickness of these shims should vary with the temperature. Some roads use such approximate rules as the following: "The proper thickness for coldest weather is $\frac{5}{16}$ of an inch; during spring and fall use $\frac{1}{8}$ of an inch, and in the very hottest weather $\frac{1}{16}$ of an inch should be allowed." This is on the basis of a 30-foot rail. When a more accurate adjustment than this is desired, it may be done by assuming some very high temperature (120° to 150° F.) as a maximum, when the joints should be *tight*; then compute in tabular form the spacing for each temperature, varying by 20° , allowing $0''.0468$ (almost exactly $\frac{3}{84}''$) for each 20° change. Such a tabular form would be about as follows (rail length 30 feet):

Temperature. . . .	150°	130°	110°	90°	70°	50°	30°	10°	-10°	-30°
Rail opening. . .	0	$\frac{3}{4}''$	$\frac{3}{8}''$	$\frac{1}{4}''$	$\frac{1}{8}''$	$\frac{1}{16}''$	$\frac{1}{32}''$	$\frac{1}{64}''$	$\frac{1}{128}''$	$\frac{1}{256}''$

One practical difficulty in the way of great refinement in this work is the determination of the real temperature of the rail when it is laid. A rail lying in the hot sun has a very much higher temperature than the air. The temperature of the rail cannot be obtained even by exposing a thermometer directly to the sun, although such a result might be the best that is easily obtainable. On a cloudy or rainy day the rail has practically the same temperature as the air; therefore on such days there need be no such trouble.

232. Chemical composition. About 98 to 99.5% of the composition of steel rails is iron, but the value of the rail, as a rail, is almost wholly dependent upon the large number of other chemical elements which are, or may be, present in very small amounts. The manager of a steel-rail mill once declared that their aim was to produce rails having in them—

Carbon.	0.32 to 0.40%
Silicon.	0.04 to 0.06%
Phosphorus.	0.09 to 0.105%
Manganese.	1.00 to 1.50%

The analysis of 32 specimens of rails on the Chic., Mil. & St. Paul R.R. showed variations as follows:

Carbon.	0.211 to 0.52%
Silicon.	0.013 to 0.256%
Phosphorus.	0.055 to 0.181%
Manganese.	0.35 to 1.63%

These quantities have the same general relative proportions as the rail-mill standard given above, the differences lying mainly in the broadening of the limits. Increasing the percentage of carbon by even a few hundredths of one per cent makes the rail harder, but likewise more brittle. If a track is well ballasted and not subject to heaving by frost, a harder and more brittle rail may be used without excessive danger of breakage, and such a rail will wear much longer than a softer tougher rail, although the softer tougher rail may be the better rail for a road having a less perfect roadbed.

A small but objectionable percentage of sulphur is sometimes found in rails, and very delicate analysis will often show the presence, in very minute quantities, of several other chemical elements. The use of a very small quantity of nickel or aluminum has often been suggested as a means of producing a more durable rail. The added cost and the uncertainty of

the amount of advantage to be gained has hitherto prevented the practical use or manufacture of such rails.

233. Testing. Chemical and mechanical testing are both necessary for a thorough determination of the value of a rail. The chemical testing has for its main object the determination of those minute quantities of chemical elements which have such a marked influence on the rail for good or bad. The mechanical testing consists of the usual tests for elastic limit, ultimate strength, and elongation at rupture, determined from pieces cut out of the rail, besides a "drop test." The drop test consists in dropping a weight of 2000 lbs. from a height of 16 to 20 feet on to the center of a rail which is supported on abutments placed three or four feet apart. The number of blows required to produce rupture or to produce a permanent set of specified magnitude gives a measure of the strength and toughness of the rail.

234. Rail wear on tangents. When the wheel loads on a rail are abnormally heavy, and particularly when the rail has but little carbon and is unusually soft, the concentrated pressure on

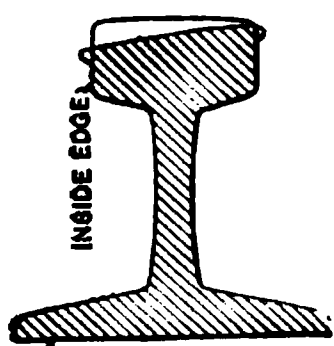


FIG. 115.

the rail is frequently greater than the elastic limit, and the metal "flows" so that the head, although greatly abraded, will spread somewhat outside of its original lines, as shown in Fig. 115. The rail wear that occurs on tangents is almost exclusively on top. Statistics show that the rate of rail wear on tangents decreases as the rails are more worn. Tests of a large number of rails on tangents have shown a rail wear averaging nearly one pound per yard per 10 000 000 tons of traffic. There is about 33 pounds of metal in one yard of the head of an 80-lb. rail. As an extreme value this may be worn down one-half, thus giving a tonnage of 165 000 000 tons for the life of the rail. Other estimates bring the tonnage down to 125 000 000 tons. Since the locomotive is considered to be responsible for one half (and possibly more) of the damage done to the rail, it is found that the rate of wear on roads with shorter trains is more rapid in proportion to the tonnage, and it

is therefore thought that the life of a rail should be expressed in terms of the number of trains. This has been estimated at 300 000 to 500 000 trains.

235. Rail wear on curves. On curves the maximum rail wear occurs on the inner side of the head of the outer rail, giving a worn form somewhat as shown in Fig. 116. The dotted line shows the nature and progress of the rail wear on the inner rail of a curve. Since the pressure on the outer rail is somewhat lateral rather than vertical, the "flow" does not take place to the same extent, if at all, on the outside, and whatever flow would take place on the inside is immediately worn off by the wheel-flange. Unlike the wear on tangents, the wear on curves is at a greater rate as the rail becomes more worn.

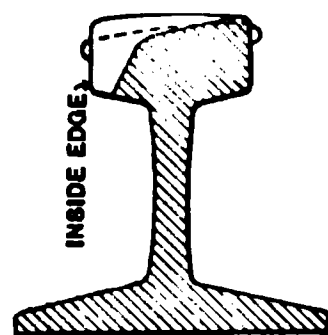


FIG. 116.

The inside rail on curves wears chiefly on top, the same as on a tangent, except that the wear is much greater owing to the longitudinal slipping of the wheels on the rail, and the lateral slipping that must occur when a rigid four-wheeled truck is guided around a curve. The outside rail is subjected to a greater or less proportion of the longitudinal slipping, likewise to the lateral slipping, and, worst of all, to the grinding action of the flange of the wheel, which grinds off the side of the head.

The results of some very elaborate tests, made by Mr. A. M. Wellington, on the Atlantic and Great Western R.R., on the wear of rails, seem to show that the rail wear on curves may be expressed by the formula: "Total wear of rails on a d degree curve in pounds per yard per 10 000 000 tons duty $= 1 + 0.03d$." "It is not pretended that this formula is strictly correct even in theory, but several theoretical considerations indicate that it may be nearly so." According to this formula the average rail wear on a 6° curve will be about twice the rail wear on a tangent. While this is approximately true, the various causes modifying the rate of rail wear (length of trains, age and quality of rails, etc.) will result in numerous and

large variations from the above formula, which should only be taken as indicating an approximate law.

236. Cost of rails. In 1873 the cost of steel rails was about \$120 per ton, and the cost of iron rails about \$70 per ton. Although the steel rails were at once recognized as superior to iron rails on account of more uniform wear, they were an expensive luxury. The manufacture of steel rails by the Bessemer process created a revolution in prices, and they have steadily dropped in price until, during the last few years, steel rails have been manufactured and sold for \$22 per ton. At such prices there is no longer any demand for iron rails, since the cost of manufacturing them is substantially the same as that of steel rails, while their durability is unquestionably inferior to that of steel rails.

CHAPTER X.

RAIL-FASTENINGS.

RAIL-JOINTS.

237. Theoretical requirements for a perfect joint. A perfect rail-joint is one that has the *same strength* and *stiffness*—no more and no less—as the rails which it joins, and which will not interfere with the regular and uniform spacing of ties. It should also be reasonably cheap both in first cost and in cost of maintenance. Since the action of heavy loads on an elastic rail is to cause a wave of translation in front of each wheel, any change in the stiffness or elasticity of the rail structure will cause more or less of a shock, which must be taken up and resisted by the joint. The greater the change in stiffness the greater the shock, and the greater the destructive action of the shock. The perfect rail-joint must keep both rail ends truly in line both laterally and vertically, so that the flange or tread of the wheel need not jump or change its direction of motion suddenly in passing from one rail to the other. A consideration of all the above requirements will show that only a perfect welding of rail-ends would produce a joint of uniform strength and stiffness which would give a uniform elastic wave ahead of each wheel. As welding is impracticable for ordinary railroad work (see § 230), some other contrivance is necessary which will approach this ideal as closely as may be.

238. Efficiency of the ordinary angle-bar. Throughout the middle portion of a rail the rail acts as a continuous girder. If we consider for simplicity that the ties are unyielding, the deflection of such a continuous girder between the ties will be but

one-fourth of the deflection that would be found if the rail were cut half-way between the ties and an equal concentrated load were divided equally between the two unconnected ends. The maximum stress for the continuous girder would be but one-half of that in the cantilevers. Joining these ends with rail-joints will give the ordinary "suspended" joint. In order to maintain uniform strength and stiffness the angle-bars must supply the deficiency. These theoretical relations are modified to an unknown extent by the unknown and variable yielding of the ties. From some experiments made by the Association of Engineers of Maintenance of Way of the P. R.R.* the following deductions were made:

1. The capacity of a "suspended" joint is greater than that of a "supported" joint—whether supported on one or three ties. (See § 240.)

2. That (with the particular patterns tested) the angle-bars alone can carry only 53 to 56% of a concentrated load placed on a joint.

3. That the capacity of the whole joint (angle-bars and rail) is only 52.4% of the strength of the unbroken rail.

4. That the ineffectiveness of the angle-bar is due chiefly to a deficiency in compressive resistance.

Although it has been universally recognized that the angle-bar is not a perfect form of joint, its simplicity, cheapness, and reliability have caused its almost universal adoption. Within a very few years other forms (to be described later) have been adopted on trial sections and have been more and more extended, until their present use is very large. The present time (1900) is evidently a transition period, and it is quite probable that within a very few years the now common angle-plate will be as unknown in standard practice as the old-fashioned "fish-plate" is at the present time.

239. Effect of rail gap at joints. It has been found that the jar at a joint is due almost entirely to the *deflection* of the joint

* Roadmasters Association of America—Reports for 1897.

and scarcely at all to the small gap required for expansion. This gap causes a drop equal to the versed sine of the arc having a chord equal to the gap and a radius equal to the radius of the wheel. Taking the extreme case (for a 30-foot rail) of a $\frac{3}{8}$ " gap and a 33" freight-car wheel, the drop is about $\frac{1}{1000}$ ". In order to test how much the jarring at a joint is due to a gap between the rails, the experiment was tried of cutting shallow notches in the top of an otherwise solid rail and running a locomotive and an inspection car over them. The resulting jarring was practically imperceptible and not comparable to the jar produced at joints. Notwithstanding this fact, many plans have been tried for avoiding this gap. The most of these plans consist essentially of some form of compound rail, the sections breaking joints. (Of course the design of the compound rail has also several other objects in view.) In Fig. 117 are shown a

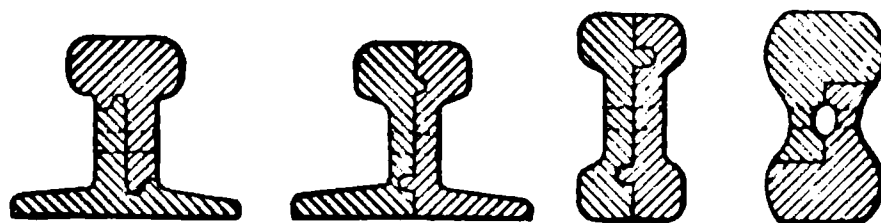


FIG. 117.—COMPOUND RAIL SECTIONS.

few of the very many designs which have been proposed. These designs have invariably been abandoned after trial. Another plan, which has been extensively tried on the Lehigh Valley R.R., is the use of mitered joints. The advantages gained by their use are as yet doubtful, while the added expense is unquestionable. The "Roadmasters Association of America" in 1895 adopted a resolution recommending mitered joints for double track, but their use does not seem to be growing.

240. "Supported," "suspended," and "bridge" joints. In a supported joint the ends of the rails are on a tie. If the angle-plates are short, the joint is entirely supported on one tie; if very long, it may be possible to place three ties under one angle-bar and thus the joint is virtually supported on three ties rather than one. In a suspended joint the ends of the rails are midway between two ties and the joint is supported by the two. There

have always been advocates of both methods, but suspended joints are more generally used than supported joints. The opponents of three-tie joints claim that either the middle tie will be too strongly tamped, thus making it a supported joint, or that, if the middle tie is weakest, the joint becomes a very long (and therefore weak) suspended joint between the outer joint-ties, or that possibly one of the outer joint-ties gives way, thus breaking the angle-plate at the joint. Another objection which is urged is that unless the bars are very long (say 44 inches, as used on the Mich. Cent. R.R.) the ties are too close for proper tamping. The best answer to these objections is the successful use of these joints on several heavy-traffic roads.

“ Bridge ”-joints are similar to suspended joints in that the joint is supported on two ties, but there is the important difference that the bridge-joint supports the rail from *underneath* and there is no transverse stress in the rail, whereas the supported joint requires the combined transverse strength of both angle-bars and rail. A serious objection to bridge-joints lies in the fact of their considerable thickness between the rail base and the tie. When joints are placed “ staggered ” rather than “ opposite ” (as is now the invariable standard practice), the ties supporting a bridge-joint must either be notched down, thus weakening the tie and promoting decay at the cut, or else the tie must be laid on a slope and the joint and the opposite rail do not get a fair bearing.

241. Failures of rail-joints. It has been observed on double-track roads that the maximum rail wear occurs a few inches beyond the rail gap at the joint in the direction of the traffic. On single-track roads the maximum rail wear is found a few inches *each* side of the joint rather than at the extreme ends of the rail, thus showing that the rail end deflects down under the wheel until (with fast trains especially) the wheel actually jumps the space and strikes the rail a few inches beyond the joint, the impact producing excessive wear. This action, which is called the “ drop,” is apt to cause the first tie beyond the joint to become depressed, and unless this tie is carefully watched and main-

tained at its proper level, the stresses in the angle-bar may actually become reversed and the bar may break at the top. The angle-bars of a suspended joint are normally in compression at the top. The mere reversal of the stresses would cause the bars

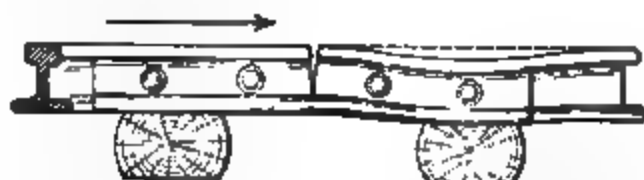


FIG. 118.—EFFECT OF "WHEEL DROP" (EXAGGERATED).

to give way with a less stress than if the stress were always the same in kind. A supported joint, and especially a three-tie joint (see § 240), is apt to be broken in the same manner.

242. Standard angle-bars.—An angle-bar must be so made as to closely fit the rails. The great multiplicity in the designs of rails (referred to in Chapter IX) results in nearly as great variety in the detailed dimensions of the angle-bars. The sections here illustrated must be considered only as types of the variable forms necessary for each different shape of rail. The absolutely essential features required for a fit are (1) the angles

FIG. 119.—STANDARD ANGLE-BAR—80-LB. RAIL. M. C. R.R.

of the upper and lower surfaces of the bar where they fit against the rail, and (2) the height of the bar. The bolt-holes in the

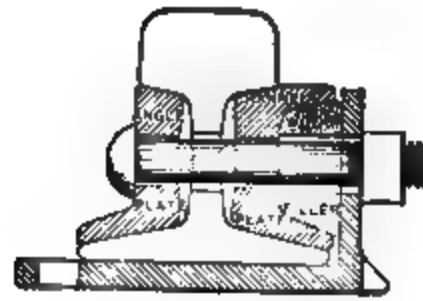
bar and rail must also correspond. The holes in the angle-plates are elongated or made oval, so that the track-bolts, which are made of corresponding shape immediately under the head, will not be turned by jarring or vibration. The holes in the rails are made of larger diameter (by about $\frac{1}{4}$ "') than the bolts, so as to allow the rail to expand with temperature.

243. Later designs of rail-joints. In Plate XVIII are shown various designs which are competing for adoption. The most prominent of these (judging from the discussion in the convention of the Roadmasters Association of America in 1897) are the "Continuous" and the "Weber." Each of them has been very extensively adopted, and where used are universally preferred to angle-plates. Nearly all the later designs embody more or less directly the principle of the bridge-joint, i.e., support the rail from underneath. An experience of several years will be required to demonstrate which form of joint best satisfies the somewhat opposed requirements of minimum cost (both initial and for maintenance) and minimum wear of rails and rolling stock.

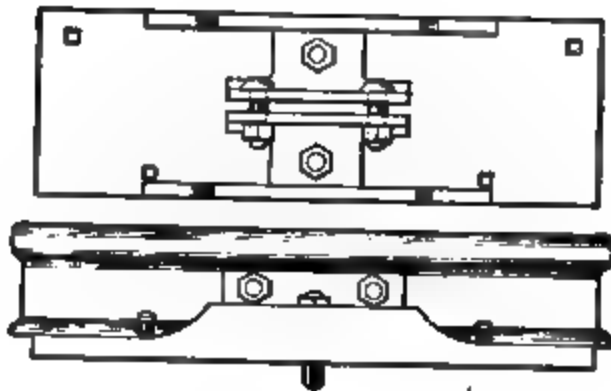
TIE-PLATES.

244. Advantages. (a) As already indicated in § 204, the life of a soft-wood tie is very much reduced by "rail-cutting" and "spike-killing," such ties frequently requiring renewal long before any serious decay has set in. It has been practically demonstrated that the "rail-cutting" is not due to the mere pressure of the rail on the tie, even with a maximum load on the rail, but is due to the impact resulting from vibration and to the longitudinal working of the rail. It has been proved that this rail-cutting is practically prevented by the use of tie-plates. (b) On curves there is a tendency to overturn the outer rail due to the lateral pressure on the side of the head. This produces a concentrated pressure of the outer edge of the base on the tie which produces rail-cutting and also draws the inner spikes. Formerly the only method of guarding

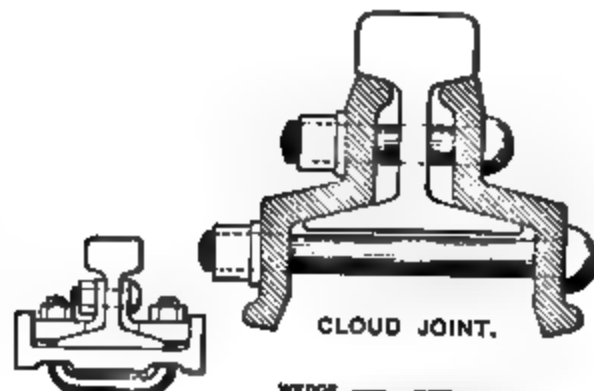
PLATE XVIII.



WEBER RAIL JOINT.



FISHER BRIDGE JOINT.



CLOUD JOINT.



ELLIOT STEEL CLAMP FROG.



SECTION THROUGH A-B.



WEIR BOLTED STIFF FROG.



ELLIOT PLATE RIVETED FROG.



SECTION THROUGH C-D.



SECTION THROUGH A-B.



WEIR SPRING-RAIL FROG.



SECTION THROUGH PLATE AT POINT.



SECTION THROUGH SPRING-HOUSING.

RAIL JOINTS AND FROGS.

(To face page 280.)

against this was by the use of "rail-braces," one pattern of which is shown in Fig. 120. But it has been found that tie-

FIG. 120.

plates serve the purpose even better, and rail-braces have been abandoned where tie-plates are used. (c) Driving spikes through holes in the plate enables the spikes on *each* side of the rail to mutually support each other, no matter in which (lateral) direction the rail may tend to move, and this probably accounts in large measure for the added stability obtained by the use of tie-plates. (d) The wear in spikes, called "necking," caused by the vertical vibration of the rail against them, is very greatly reduced. (e) The cost is very small compared with the value of the added life of the tie, the large reduction in the work of track maintenance, and the smoother running on the better track which is obtained. It has been estimated that by the use of tie-plates the life of hard-wood ties is increased from one to three years, and the life of soft-wood ties is increased from three to six years. From the very nature of the case, the value of tie-plates is greater when they are used to protect soft ties.

245. Elements of the design. The earliest forms of tie-plates were flat on the bottom, but it was soon found that they would work loose, allow sand and dirt to get between the rail and the plate and also between the plate and the tie, which would cause excessive wear. Such plates are also apt to produce an objectionable rattle. Another fault of the earlier designs was the use of plates so thin that they would buckle. The latest designs have flanges or "teeth" formed on the lower surface which penetrate the tie about $\frac{1}{4}$ " to $1\frac{1}{8}$ ". Opinion is still divided on the question of whether these teeth should run with the grain

or across the grain. If the flanges run with the grain, they generally extend the whole length of the tie-plate—as in the Wolhaupter design. If the grain is to be cut crosswise, several teeth about 1" wide will be used—as in the Goldie design.

FIG. 121.—TIE-PLATES.

It is a very important feature that the spike-holes should be so punched that the spikes will fit closely to the base of the rail. Otherwise a lateral motion of the rail will be permitted which will defeat one of the main objects of the use of the plate.

Another unsettled detail is the use of "shoulders" on the upper surface. On the one hand it is claimed that the use of shoulders relieves the spikes of side pressure from the rail and prevents "necking." On the other hand it is claimed that if the plain plate is once properly set with new spikes (at least with spikes not already necked) the spikes will not neck appreciably, and that, as the shouldered plates cost more, the additional expenditure is unnecessary.

The above designs should be studied with reference to the manner in which they fulfill the requirements which have been already stated. As in the case of rail-joints, the best forms of tie-plates are of comparatively recent design, and experience with them is still insufficient to determine beyond all question which designs are the best.

246. Methods of setting. A very important detail in the process of setting the tie-plates on the ties is that the flanges or teeth should penetrate the tie as far as desired when the plates are first put in position. It requires considerable force to press the teeth into a tie. In a few cases trackmen have depended on the easy process of waiting for passing trains to force the teeth

down. Until the teeth are down the spikes cannot be driven home, and this apparently cheap and easy process results in loose spikes and rails. If the trackmen neglect even temporarily to tighten these spikes, it will become impossible to make them tight ultimately. The plates are generally pounded into place with a 10- to 16-pound sledge-hammer. A very good method was adopted once during the construction of a bridge when a pile-driver was at hand. The bridge-ties were placed under the pile-hammer. The plates, accurately set to gauge, were then forced in by a blow from the 3000-lb. hammer falling 2 or 3 feet.

SPIKES.

247. Requirements. The rails must be held to the ties by a fastening which will not only give sufficient resistance, but which will retain its capacity for resistance. It must also be cheap and easily applied. The ordinary track-spike fulfills the last requirements, but has comparatively small resisting power, compared with screws or bolts. Worse than all, the tendency to vertical vibration in the rail produces a series of upward pulls on the spike that soon loosens it. When motion has once begun the capacity for resistance is greatly reduced, and but little more vibration is required to pull the spike out so much that redriving is necessary. Driving the spike to place again in the same hole is of small value except as a very temporary expedient, as its holding power is then very small. Redriving the spikes in new holes very soon "spike-kills" the tie. Many plans have been devised to increase the holding power of spikes, such as making them jagged, twisting the spike, swelling the spike at about the center of its length, etc. But it has been easily demonstrated that the fibers of the wood are generally so crushed and torn by driving such spikes that their holding power is less than that of the plain spike.



FIG. 122.

The ordinary spike (see Fig. 122) is made with a square cross-section which is uniform through the middle of its length, the lower $1\frac{1}{2}$ " tapering down to a chisel edge, the upper part swelling out to the head. The Goldie spike (see Fig. 123) aims to improve this form by reducing to a minimum the destruction of the fibers. To this end, the sides are made smooth, the edges are clean-cut, and the point, instead of being chisel-shaped, is ground down to a pyramidal form. Such fiber-cutting as occurs is thus accomplished without much crushing, and the fibers are thus pressed away from the spike and slightly downward. Any tendency to draw the spike will therefore cause

the fibers to press still harder on the spike and thus increase the resistance.

248. Driving. The holding power of a spike depends largely on how it is driven. If the blows are eccentric and irregular in direction, the hole will be somewhat enlarged and the holding power largely decreased. The spikes on each side of the rail in any one tie should not be directly opposite, but should be staggered. Placing them directly opposite will tend to split the tie, or at least decrease the holding power of the spikes. The direction of staggering should be reversed in the two pairs of spikes in any one tie (see Fig. 124). This will tend to prevent any twisting of the tie in the ballast, which would otherwise loosen the rail from the tie.

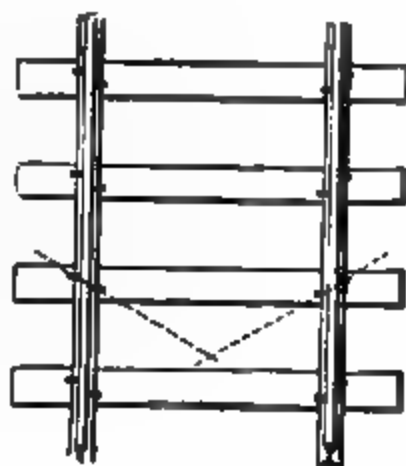


FIG. 124. SPIKE-DRIVING.

249. Screws and bolts. The use of these abroad is very extensive, but their use in this country has not passed the experimental stage. The screws are "wood"-screws (see Fig. 125), having large square heads, which are screwed down with a track-wrench. Holes, having the same diameter as the base of the screw-threads, should first be bored into the tie, at exactly the right position and at the proper angle with the vertical.

A light wooden frame is sometimes used to guide the auger at the proper angle. Sometimes the large head of the screw bears directly against the base of the rail, as with the ordinary spike. Other designs employ a plate, made to fit the rail on one side, bearing on the tie on the other side, and through which the screw passes. These screws cost much more than spikes and require more work to put in place, but their holding power is much greater and the work of track maintenance is very much less. Screw-bolts, passing entirely through the tie, having the head at the bottom of the tie and the nut on the upper side, are also used abroad. These are quite difficult to replace, requiring that the ballast be dug out beneath the tie, but on the other hand the occasions for replacing such a bolt are comparatively rare, as their durability is very great. The



FIG. 125.

FIG. 126.

use of screws or bolts increases the life of the tie by the avoidance of "spike-killing." It is capable of demonstration that the reduced cost of maintenance and the resulting improvement in track would much more than repay the added cost of screws and bolts, but it seems impossible to induce railroad directors to authorize a large and immediate additional expenditure to make an annual saving whose value, although unquestionably considerable, cannot be exactly computed.

250. "Wooden spikes." Among the regulations for track-laying given in § 208, mention was made of wooden "spikes," or plugs, which are used to fill up the holes when spikes are withdrawn. The value of the policy of filling up these holes is unquestionable, since the expense is insignificant compared with the loss due to the quick and certain decay of the tie if these holes are allowed to fill with water and remain so. But the method of making these plugs is variable. On some roads they are "hand-made" by the trackmen out of otherwise useless

scraps of lumber, the work being done at odd moments. This policy, while apparently cheap, is not necessarily so, for the hand-made plugs are irregular in size and therefore more or less inefficient. It is also quite probable that if a track gang is required to make their own plugs, they may spend time on these very cheap articles which could be more profitably employed otherwise. Since the holes made by the spikes are larger at the top than they are near the bottom, the plugs should *not* be of uniform cross section but should be slightly wedge-shaped. The "Goldie tie-plug" (see Fig. 127) has been designed to fill these requirements. Being machine-

FIG. 127. made, they are uniform in size; they are of a shape which will best fit the hole; they can be furnished of any desired wood, and at a cost which makes it a wasteful economy to attempt to cut them by hand.

TRACK-BOLTS AND NUT-LOCKS.

251. Essential requirements. The track-bolts must have sufficient strength and must be screwed up tight enough to hold the angle-plates against the rail with sufficient force to develop the full transverse strength of the angle-bars. On the other hand the bolts should not be screwed so tight that slipping may not take place when the rail expands or contracts with temperature. It would be impossible to screw the bolts tight enough to prevent

slipping during the contraction due to a considerable fall of temperature on a straight track, but when the track is curved, or when expansion takes place, it is conceivable that the resistance of the ties in the ballast to lateral motion may be less than the resistance at the joint. A test to determine this resistance was made by Mr. A. Torrey, chief engineer of the Mich. Cent. R.R., using 80-lb. rails and ordinary angle-bars, the bolts being screwed up as usual. It required a force of about 31000 to 35000 lbs. to start the joint, which would be equivalent to the stress induced by a change of temperature of about 22° . But if the central angle of any given curve is small, a comparatively small lateral component will be sufficient to resist a compression of even 35000 lbs. in the rails. Therefore there will ordinarily be no trouble about having the joints screwed too tight. The vibration caused by the passage of a train reduces the resistance to slipping. This vibration also facilitates an objectionable feature, viz., loosening of the nuts of the track-bolts. The bolt is readily prevented from turning by giving it a form which is *not* circular immediately under the head and making corresponding holes in the angle-plate. Square holes would answer the purpose, except that the square corners in the holes in the angle-plates would increase the danger of fracture of the plates. Therefore the holes (and also the bolts, under the head) are made of an oval form, or perhaps a square form with rounded corners, avoiding angles in the outline.

The nut-locks should be simple and cheap, should have a life at least as long as the bolt, should be effective, and should not lose their effectiveness with age. Many of the designs that have been tried have been failures in one or more of these particulars, as will be described in detail below.

252. Design of track-bolts. In Fig. 128 is shown a common design of track-bolt. In its general form this represents the bolt used on nearly all roads, being used not only with the common angle-plates, but also with many of the improved designs of rail-joints. The variations are chiefly a general increase in size to correspond with the increased

weight of rails, besides variations in detail dimensions which are frequently unimportant. The diameter is usually $\frac{3}{4}$ " to $\frac{1}{2}$ "; 1" bolts are sometimes used for the heaviest sections of rails. As to length, the bolts should not extend more than $\frac{1}{2}$ " outside of the nut when it is screwed up. If it extends farther than this, it is liable to be broken off by a possible derailment at that point. The lengths used vary from $3\frac{1}{2}$ ", which may be used with 60 lbs. rails, to 5", which is required with 100-lb. rails. The length required depends somewhat on the type of nut-lock used.

FIG. 128 — TRACK-BOLT.

253. Design of nut-locks. The designs for nut-locks may be divided into three classes: (a) those depending entirely on an elastic washer which absorbs the vibration which might otherwise induce turning; (b) those which jam the threads of the bolt and nut so that, when screwed up, the frictional resistance is too great to be overcome by vibration; (c) the "positive" nut-locks—those which mechanically hold the nut from turning. Some of the designs combine these principles to some extent. The "vulcanized fiber" nut-lock is an example of the first class. It consists essentially of a rubber washer which is protected by an iron ring. When first placed this lock is effective, but the rubber soon hardens and loses its elasticity and it is then ineffective and worthless. Another illustration of class (a) is the use of wooden blocks, generally of 1" to 2" oak, which extend the entire length of the angle-bar, a single piece forming the washer for the four or six bolts of a joint. This form is cheap, but the wood soon shrinks, loses its elasticity, or decays so that it soon becomes worthless, and it requires constant adjustment to keep it in even tolerable condition. The "Verona" nut-lock is another illustration of class (a) which also combines some of the positive elements of class (c). It is made of

tempered steel and, as shown in Fig. 129, is warped and has sharp edges or points. The warped form furnishes the element of elastic pressure when the nut is screwed up. The steel being harder than the iron of the angle-bar or of the nut, it bites into them, owing to the great pressure that must exist

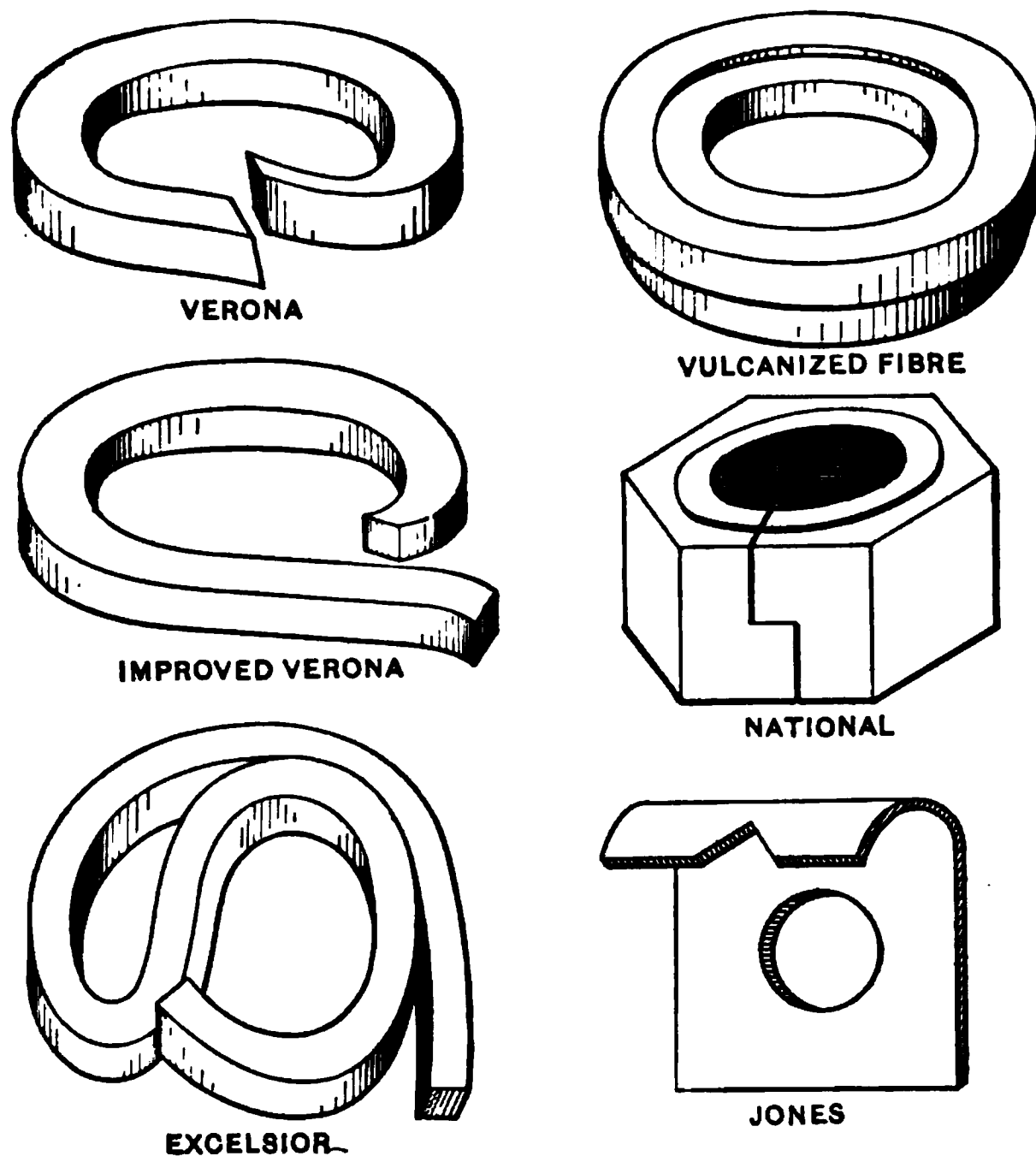


FIG. 129.—TYPES OF NUT-LOCKS.

when the washer is squeezed nearly flat, and thus prevents any *backward* movement, although forward movement (or tightening the bolt) is not interfered with. The “National” nut-lock is a type of the second class (*b*), in which, like the “Harvey” nut-lock, the nut and lock are combined in one piece. With six-bolt angle-bars and 30-foot rails, this means a saving of 2112 pieces on each mile of single track. The “National” nuts are open on one side. The hole is drilled and the thread is cut slightly smaller than the bolt, so that when the nut is screwed

up it is forced slightly open and therefore presses on the threads of the bolt with such force that vibration cannot jar it loose. Unlike the "National" nut, the "Harvey" nut is solid, but the form of the thread is progressively varied so that the thread pinches the thread of the bolt and the frictional resistance to turning is too great to be affected by vibration.

The "Jones" nut-lock, belonging to class (c), is a type of a nut-lock that does not depend on elasticity or jamming of screw-threads. It is made of a thin flexible plate, the square part of which is so large that it will not turn after being placed on the bolt. After the nut is screwed up, the thin plate is bent over so that the re-entrant angle of the plate engages the corner of the nut and thus mechanically prevents any turning. The metal is supposed to be sufficiently tough to endure without fracture as many bendings of the plate as will ever be desired. Nut-locks of class (c) are not in common use.

CHAPTER XI.

SWITCHES AND CROSSINGS.

SWITCH CONSTRUCTION.

254. Essential elements of a switch. Flanges of some sort are a necessity to prevent car-wheels from running off from the rails on which they may be moving. But the flanges, although a necessity, are also a source of complication in that they require some special mechanism which will, when desired, guide the wheels out from the controlling influence of the main-line rails. This must either be done by raising the wheels high enough so that the flanges may pass *over* the rails, or by breaking the continuity of the rails in such a way that channels or "flange spaces" are formed *through* the rails. An ordinary stub switch breaks the continuity of the main-line rails in three places, two of them at the switch-block and one at the frog. The Wharton switch avoids two of these breaks by so placing inclined planes that the wheels, rolling on their flanges, will surmount these inclines until they are a little higher than the rails. Then the wheels on the side toward which the switch runs are guided over and across the main rail on that side. This rise being accomplished in a short distance, it becomes impracticable to operate these switches except at slow speeds, as any sudden change in the path of the center of gravity of a car causes very destructive jars both to the switch and to the rolling stock. The other general method makes a break in one main rail (or both) at the switch-block. In both methods the wheels are led to one side by means of the "lead rails," and finally one line of wheels passes *through* the main rail on that side by means of a "frog." There are some designs by which even this break in the main rail is avoided, the wheels being led *over* the main rail by means

of a short *movable* rail which is on occasion placed across the main rail, but such designs have not come into general use.

255. Frogs. Frogs are provided with two channel-ways or “flange spaces” through which the flanges of the wheels move. Each channel cuts out a parallelogram from the tread area. Since the wheel-tread is always wider than the rail, the wing rails will support the wheel not only across the space cut out by

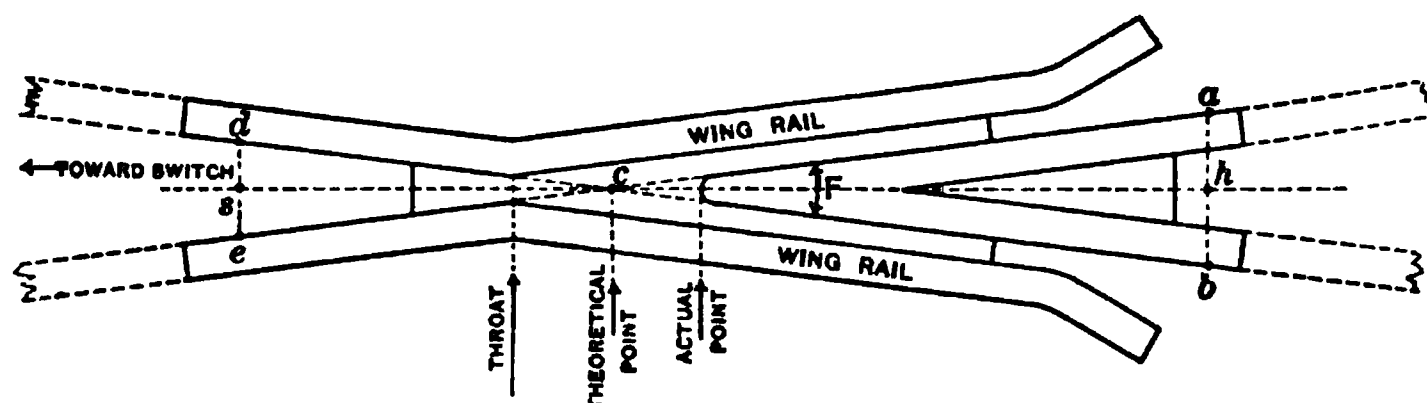


FIG. 130.—DIAGRAMMATIC DESIGN OF FROG.

the channel, but also until the tread has passed the point of the frog and can obtain a broad area of contact on the tongue of the frog. This is the theoretical idea, but it is very imperfectly realized. The wing rails are sometimes subjected to excessive wear owing to “hollow treads” on the wheels—owing also to the frog being so flexible that the point “ducks” when the wheel approaches it. On the other hand the sharp point of the frog will sometimes cause destructive wear on the tread of the wheel. Therefore the tongue of the frog is not carried out to the sharp theoretical point, but is purposely somewhat blunted. But the break which these channels make in the continuity of the tread area becomes extremely objectionable at high speeds, being mutually destructive to the rolling stock and to the frog. The jarring has been materially reduced by the device of “spring frogs”—to be described later. Frogs were originally made of cast iron—then of cast iron with wearing parts of cast steel, which were fitted into suitable notches in the cast iron. This form proved extremely heavy and devoid of that elasticity of track which is necessary for the safety of rolling stock and track at high speeds. The present universal practice is to build the frog up of pieces of rails which are cut or bent as required. These pieces of rails (at least four) are sometimes

assembled by riveting them to a flat plate, but this method is now but little used, except for very light work. The usual practice is now chiefly divided between "bolted" and "keyed" frogs. In each case the space between the rails, except a sufficient flange-way, is filled with a cast-iron filler and the whole assemblage of parts is suitably bolted or clamped together, as is illustrated in Plate XVIII. The operation of a spring-rail frog is evident from the figure. Since a siding is usually operated at slow speed, while the main track may be operated at fast speed, a spring-rail frog will be so set that the tread is continuous for the main track and broken for the siding. This also means that the spring rail will only be moved by trains moving at a (presumably) slow speed on to the siding. For the fast trains on the main line such a frog is substantially a "fixed" frog and has a tread which is practically continuous.

256. To find the frog number. The frog number (n) equals the ratio of the distance of any point on the tongue of the frog from the theoretical point of the frog divided by the width of the tongue at that point, i.e. $= hc \div ab$ (Fig. 130). This value may be directly measured by applying any convenient unit of measure (even a knife, a short pencil, etc.) to some point of the tongue where the width just equals the unit of measure, and then noting how many times the unit of measure is contained in the distance from that place to the theoretical point. But since c , the theoretical point, is not so readily determinable with exactitude, it being the imaginary intersection of the gauge lines, it may be more accurate to measure de , ab , and hs ; then n , the frog number, $= hs \div (ab + de)$. If the frog angle be called F , then

$$n = hc \div ab = hs \div (ab + de) = \frac{1}{2} \cot \frac{1}{2} F;$$

i.e.. $\cot \frac{1}{2} F = 2n.$

257. Stub switches. The use of these, although once nearly universal, has been practically abandoned as turnouts from *main track* except for the poorest and cheapest roads. In some States, their use on main track is prohibited by law. They

have the sole merit of cheapness with adaptability to the circumstances of very light traffic operated at slow speed when a considerable element of danger may be tolerated for the sake of economy. The rails from *A* to *B* (see Fig. 131*) are not fastened

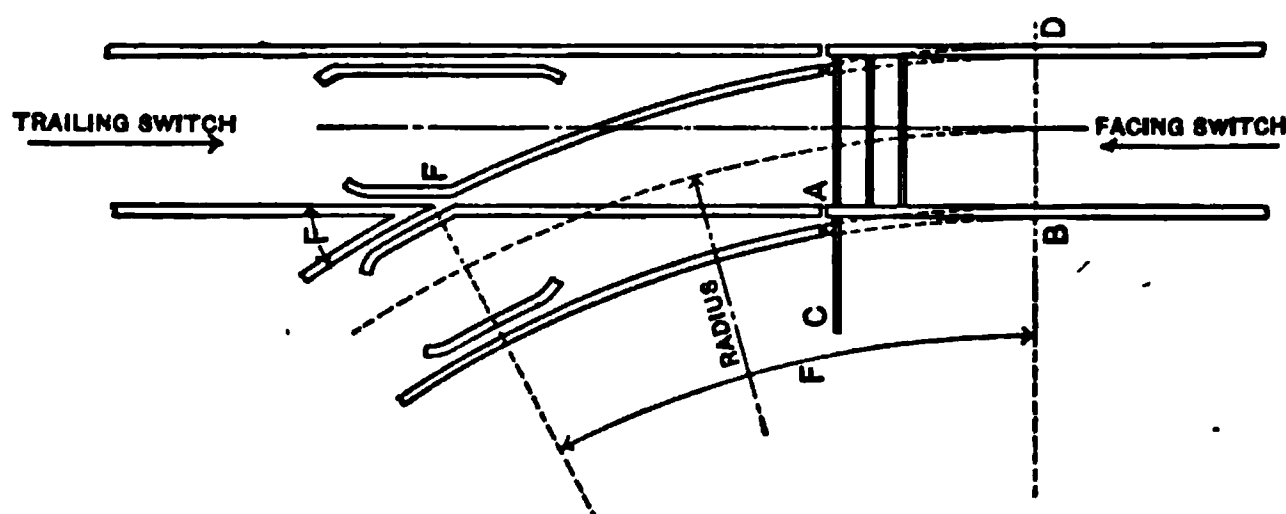


FIG. 131.—STUB SWITCH.

to the ties; they are fastened to each other by tie-rods which keep them at the proper gauge; at and back of *B* they are securely spiked to the ties, and at *A* they are kept in place by the connecting bar (*C*) fastened to the switch-stand. One great objection to the switch is that, in its usual form, when operated as a trailing switch, a derailment is inevitable if the switch is misplaced. The very least damage resulting from such a derailment must include the bending or breaking of the tie-rods of the switch-rail. Several devices have been invented to obviate this objection, some of which succeed very well mechanically, although their added cost precludes any economy in the total cost of the switch. Another objection to the switch is the looseness of construction which makes the switches objectionable at high speeds. The gap of the rails at the head-block is always considerable, and is sometimes as much as two inches. A

* The student should at once appreciate that in Fig. 131, as well as in nearly all the remaining figures in this chapter, it becomes necessary to use excessively large frog angles, short radii, and a very wide gauge in order to illustrate the desired principles with figures which are sufficiently small for the page. In fact, the proportions used in the figures are such that serious mechanical difficulties would be encountered if they were used. These difficulties are here ignored because they can be neglected in the proportions used in practice.

driving-wheel with a load of 12000 to 20000 pounds, jumping this gap with any considerable velocity, will do immense damage to the farther rail end, besides producing such a stress in the construction that a breakage is rendered quite likely, and such a breakage might have very serious consequences.

258. Point switches. The essential principle of a point switch is illustrated in Fig. 132. As is shown, one main rail and also one of the switch-rails is unbroken and immovable.

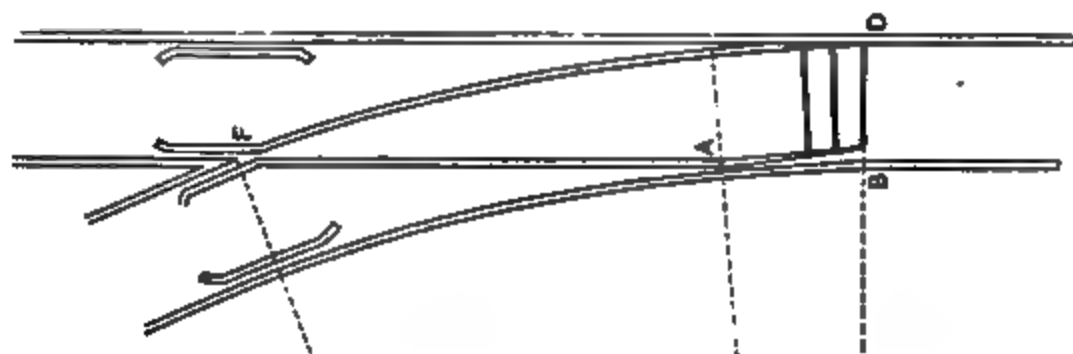


FIG. 132.—POINT SWITCH.

The other main rail (from *A* to *F*) and the corresponding portion of the other lead rail are substantially the same as in a stub switch. A portion of the main rail (*AB*) and an equal length of the opposite lead rail (usually 15 to 24 feet long) are fastened together by tie-rods. The end at *A* is jointed as usual and the other end is pointed, both sides being trimmed down so that the feather edge at *B* includes the web of the rail. In order to retain in it as much strength as possible, the point-rail is raised so that it rests on the base of the stock-rail, one side of the base of the point-rail being entirely cut away. As may be seen in Fig. 133, although the influence of the point of the rail in moving the wheel-flange away from the stock-rail is really zero at that point, yet the rail has all the strength of the web and about one-half that of the base—a very fair angle-iron.

FIG. 133.

The planing runs back in *straight* lines, until at about six or seven feet back from the point the full width of the head is

obtained. The full width of the base will only be obtained at about 13 feet from the point. An 80-lb. rail is 5 inches

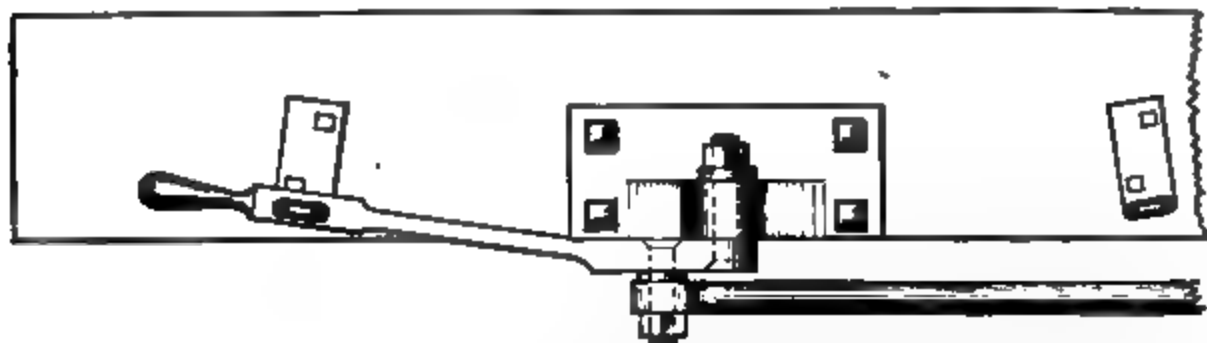


FIG. 134.—GROUND LEVER FOR THROWING A SWITCH.

wide at the base. Allowing $\frac{1}{4}$ " more for a spike between the rails, this gives $5\frac{1}{4}$ " as the minimum width between rail centers at the joint. The minimum angle of the switch-point (using a 15-foot point rail) is therefore the angle whose tangent is $\frac{5.75}{15 \times 12} = .03914$, which is the tangent of $1^\circ 50'$. Switch-rails are sometimes used with a length of 24 feet, which reduces the angle of the switch-point to $1^\circ 09'$.

259. Switch-stands. The simplest and cheapest form is the "ground lever," which has no target. The radius of the circle described by the connecting-rod pin is precisely one-half the throw. From the nature of the motion the device is practically self-locking in either position, padlocks being only used to prevent malicious tampering. The numerous designs of upright stands are always combined with targets, one design of which is illustrated in Fig. 135. When the road is equipped with interlocking signals, the switch-throw mechanism forms a part of the design.

FIG. 135.

260. Tie-rods. These are fastened to the webs of the rails by means of lugs which are bolted on, there

being usually a hinge-joint between the rod and the lug. Four such tie-rods are generally necessary. The first rod is sometimes made without hinges, which gives additional stiffness to the comparatively weak rail-points. The old fashioned tie-rod, having jaws fitting the base of the rail, was almost universally used in the days of stub switches. One great inconvenience in their use lies in the fact that they must be slipped on, one by one, over the *free* ends of the switch-rails. Sometimes the lugs are fastened to the rail-webs by rivets instead of bolts.

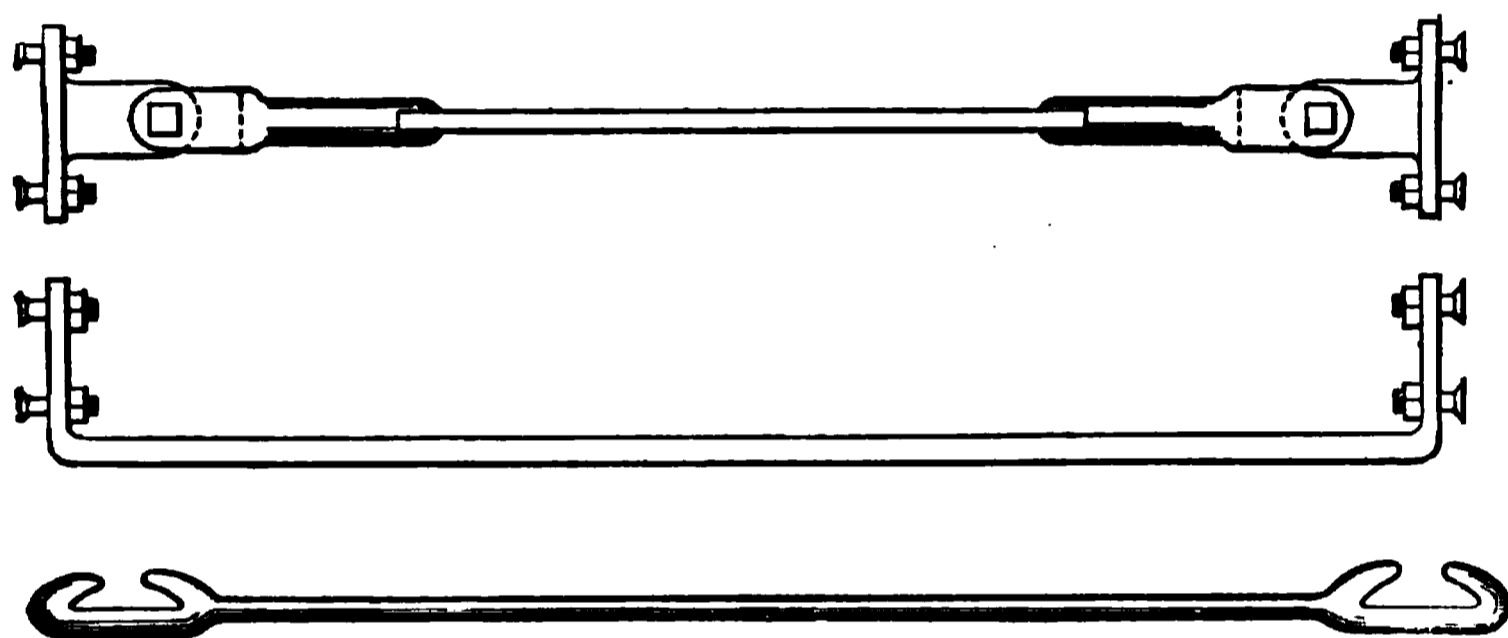


FIG. 136.—FORMS OF TIE-RODS.

261. Guard-rails. As shown in Figs. 131 and 132, guard-rails are used on both the main and switch tracks opposite the frog-point. Their function is not only to prevent the possibility of the wheel-flanges passing on the wrong side of the frog-point, but also to save the side of the frog-tongue from excessive wear. The necessity for their use may be realized by noting the very apparent wear usually found on the side of the head of the guard-rail. The flange-way space between the heads of the guard-rail and wheel-rail therefore becomes a definite quantity and should equal about two inches. Since this is less than the space between the heads of ordinary (say 80-pound) rails when placed base to base, to say nothing of the $\frac{3}{4}$ " necessary for spikes, it becomes necessary to cut the flange of the guard-rail. The length of the rail is made from 10 to 15 feet, the ends being bent as shown in Fig. 132, so as to

prevent the possibility of the end of the rail being struck by a wheel-flange.

MATHEMATICAL DESIGN OF SWITCHES.

In all of the following demonstrations regarding switches, turnouts, and crossovers, the lines are assumed to represent the *gauge-lines*—i.e., the lines of the *inside* of the head of the rails.

262. Design with circular lead-rails. The simplest method is to consider that the lead-rails curve out from the main track-rails by arcs of circles which are tangent to the main rails and which extend to the frog-point F . The simple curve from D to F is of such radius that $(r + \frac{1}{2}g) \text{ vers } F = g$, in which F = the frog angle, g = gauge, L = the "lead" (BF), and r = the radius of the center of the switch-rails.

FIG. 187.

$$\therefore r + \frac{1}{2}g = \frac{g}{\text{vers } F} \quad (74)$$

Also $BF + BD = \cot \frac{1}{2}F$; $BD = g$; $BF = L$.

$$\therefore L = g \cot \frac{1}{2}F \quad (75)$$

Also $L = (r + \frac{1}{2}g) \sin F$; (76)

$$QT = 2r \sin \frac{1}{2}F. \quad (77)$$

These formulæ involve the angle F . As shown in Table III, the angles (F) are always odd quantities, and their trigonometric functions are somewhat troublesome to obtain closely with ordinary tables. The formulæ may be simplified by substituting the frog-number n , from the relation that $n = \frac{1}{2} \cot \frac{1}{2}F$. Since

$$r - \frac{1}{2}g = L \cot F \text{ and } r + \frac{1}{2}g = L \text{ cosec } F,$$

and the length of the switch-rails is

$$QK = r \sin KOQ. \quad . \quad . \quad . \quad . \quad . \quad (81)$$

These relations develop another disadvantage in the use of a stub switch. The required value of BG , using a No. 10 frog and 80-pound rail, is 30.1 feet—slightly more than a full rail length. It would be unsafe to leave so much of the track unspiked from the ties. Whether this is obviated by spiking down a portion of the switch-rails (virtually shortening the lead) or by moving the switch-block nearer the heel of the switch (shortening the switch-rails), but still maintaining the required throw, the theoretical accuracy of the curve is hopelessly lost.

263. Effect of straight frog-rails. A portion of the ends of the rails of a frog are free and *may* be bent to conform to the

switch-rail curve, but there is a considerable portion which is fitted to the cast-iron filler, and this portion is always straight. Call the length of this straight portion back from the frog-point f ($= FH$, Fig. 138). Then we have

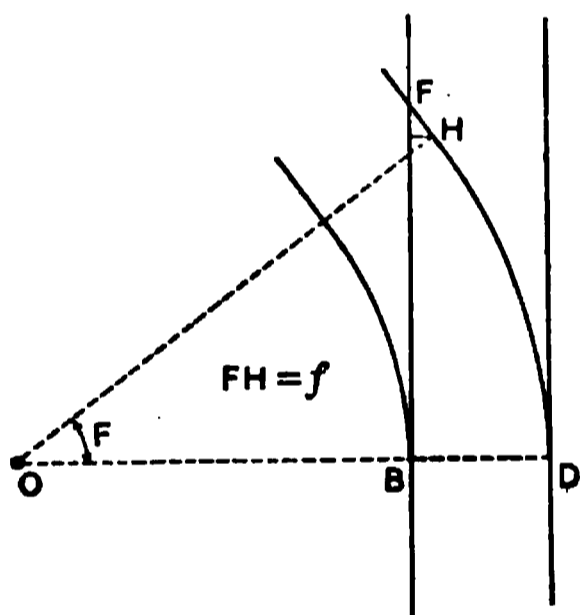


FIG. 138.

$$\begin{aligned} r + \frac{1}{2}g &= (g - f \sin F) \div \text{vers } F \\ &= \frac{g}{\text{vers } F} - f \cot \frac{1}{2}F \\ &= \frac{g}{\text{vers } F} - 2fn. \quad . \quad . \quad . \quad (82) \end{aligned}$$

$$\begin{aligned} BF = L &= (g - f \sin F) \cot \frac{1}{2}F + f \cos F \\ &= 2gn - f \sin F \cot \frac{1}{2}F + f \cos F \\ &= 2gn - f(1 + \cos F) + f \cos F \\ &= 2gn - f. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (83) \end{aligned}$$

Since $r - \frac{1}{2}g = (L - f \sec F) \cot F$, and

$$r + \frac{1}{2}g = (L - f \cos F) \text{cosec } F,$$

$$r = \frac{1}{2}L (\cot F + \operatorname{cosec} F) - \frac{1}{2}f \sec F \cot F - \frac{1}{2}f \cos F \operatorname{cosec} F$$

$$= Ln - \frac{1}{2}f \left(\frac{1 + \cos F}{\sin F} \right).$$

$$r = Ln - \frac{1}{2}f \cot \frac{1}{2}F$$

$$= Ln - fn. \quad \text{Then from (83)}$$

$$r = 2gn^2 - 2fn. \quad . \quad . \quad . \quad . \quad . \quad (84)$$

264. Effect of straight point-rails. The “point switches,” now so generally used, have *straight* switch-rails. This requires an *angle* in the alignment rather than turning off by a tangential curve. The angle is, however, very small (between 1° and 2°), and the disadvantages of this angle are small compared with the very great advantages of the device.

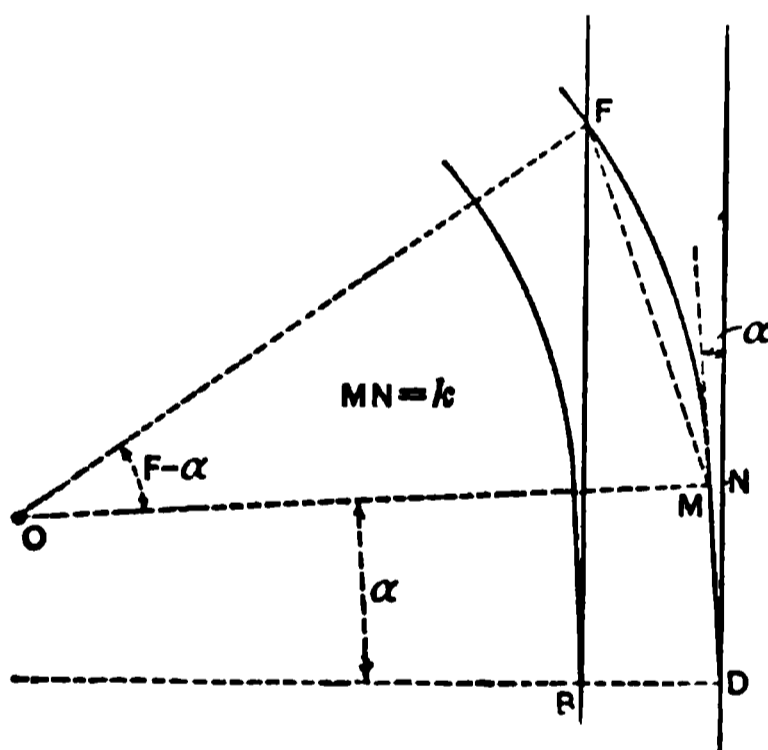


FIG. 139.

$$FM = \frac{g - k}{\sin \frac{1}{2}(F + \alpha)};$$

$$r + \frac{1}{2}g = \frac{FM}{2 \sin \frac{1}{2}(F - \alpha)}$$

$$= \frac{g - k}{2 \sin \frac{1}{2}(F + \alpha) \sin \frac{1}{2}(F - \alpha)}$$

$$= \frac{g - k}{\cos \alpha - \cos F}. \quad . \quad . \quad . \quad . \quad . \quad (85)$$

$$BF = L = FM \cos \frac{1}{2}(F + \alpha) + DN$$

$$= (g - k) \cot \frac{1}{2}(F + \alpha) + DN. \quad (86)$$

265. Combined effect of straight frog-rails and straight point-rails. It becomes necessary in this case to find a curve which shall be tangent to both the point-rail and the frog-rail. The curve therefore begins at M , its tangent making an angle of α (usually $1^\circ 50'$) with the main rail, and runs to H . The central

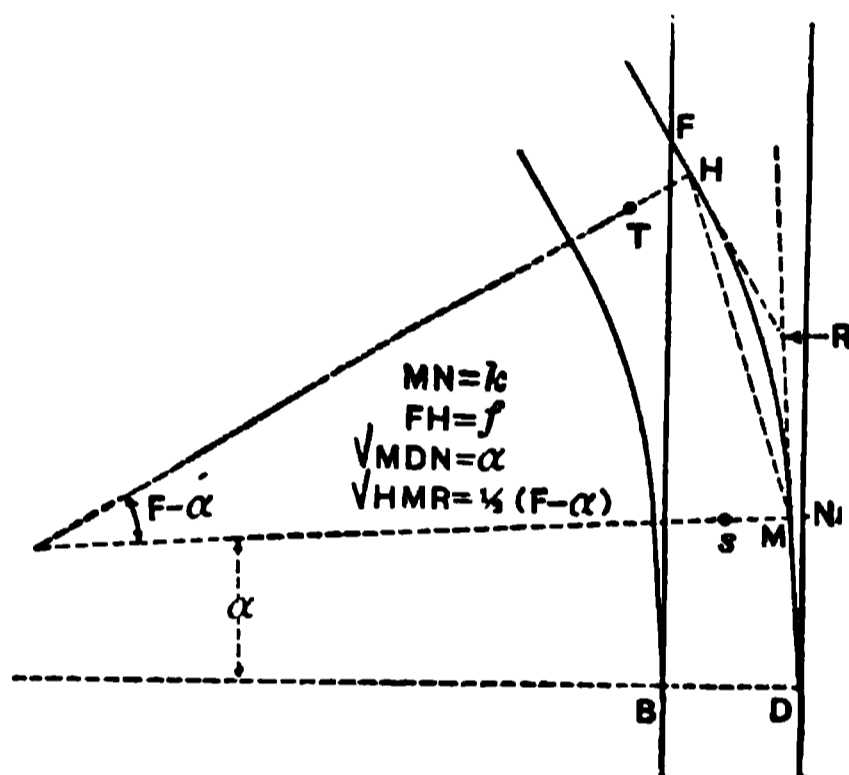


FIG. 140.

angle of the curve is therefore $(F - \alpha)$. The angle of the chord HM with the main rails is therefore

$$\frac{1}{2}(F - \alpha) + \alpha = \frac{1}{2}(F + \alpha);$$

$$HM = \frac{g - f \sin F - k}{\sin \frac{1}{2}(F + \alpha)};$$

$$r + \frac{1}{2}g = \frac{HM}{2 \sin \frac{1}{2}(F - \alpha)}$$

$$= \frac{g - f \sin F - k}{2 \sin \frac{1}{2}(F + \alpha) \sin \frac{1}{2}(F - \alpha)}$$

$$= \frac{g - f \sin F - k}{\cos \alpha - \cos F}; \quad (87)$$

$$ST = 2r \sin \frac{1}{2}(F - \alpha). \quad (88)$$

$$\begin{aligned} BF = L &= HM \cos \frac{1}{2}(F + \alpha) + f \cos F + DN \\ &= (g - f \sin F - k) \cot \frac{1}{2}(F + \alpha) + f \cos F + DN. \end{aligned} \quad (89)$$

It may be more simple, if $(r + \frac{1}{2}g)$ has already been computed, to write

$$\begin{aligned} L &= 2(r + \frac{1}{2}g) \sin \frac{1}{2}(F - \alpha) \cos \frac{1}{2}(F + \alpha) + f \cos F + DN \\ &= (r + \frac{1}{2}g)(\sin F - \sin \alpha) + f \cos F + DN. \end{aligned} \quad (90)$$

266. Comparison of the above methods. Computing values for r and L by the various methods, on the uniform basis of a No. 9 frog, standard gauge $4' 8\frac{1}{2}''$, $f = 3'.37$, $k = 5\frac{3}{4}'' = 0'.479$, $DN = 15' 0''$, and $\alpha = 1^\circ 50'$, we may tabulate the comparative results:

	§ 262. Simple circle Curved frog-r. Curved switch-r.	§ 263. Straight frog-r. Curved switch-r.	§ 264. Curved frog-r. Straight switch-r.	§ 265. Straight frog r. Straight switch-r.
r	762.75	702.00	747.48	681.16
Deg. of curve	7° 31'	8° 10'	7° 40'	8° 25'
L	84.75	81.87	74.00	72.13

This shows that the effect of using straight frog-rails and straight switch-rails is to sharpen the curve and shorten the lead in each case separately, and that the combined effect is still greater. The effect of the straight switch-rails is especially marked in reducing the length of lead, and therefore Eq. 78 to 80, although having the advantage of extreme simplicity, cannot be used for point-switches without material error. The effect of the straight frog-rail is less, and since it can be materially reduced by bending the free end of the frog-rails, the influence of this feature is frequently ignored, the frog-rails are assumed to be curved and Eq. 85 and 86 are used. (See § 276 for a further discussion of this point.)

267. Dimensions for a turnout from the OUTER side of a curved track. In this demonstration the switch-rails will be considered as uniformly circular from the switch-points to the frog-point.

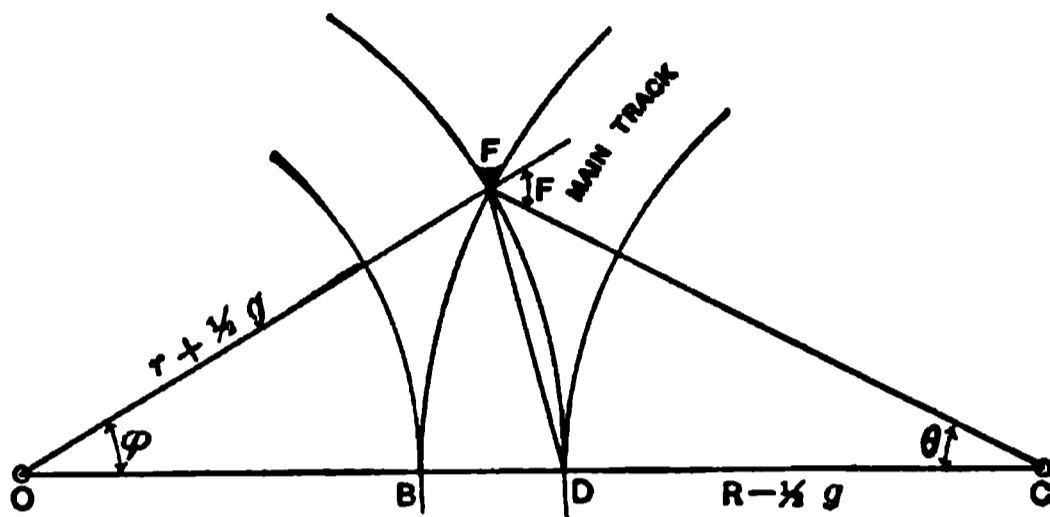


FIG. 141.

In the triangle FCD (Fig. 141) we have

$$(FC + CD) : (FC - CD) :: \tan \frac{1}{2}(FDC + DFC) : \tan \frac{1}{2}(FDC - DFC);$$

but $\frac{1}{2}(FDC + DFC) = 90^\circ - \frac{1}{2}\theta$

and $\frac{1}{2}(FDC - DFC) = \frac{1}{2}F$.

Also $FC + CD = 2R$ and $FC - CD = g$;

$$\therefore 2R : g :: \cot \frac{1}{2}\theta : \tan \frac{1}{2}F \\ :: \cot \frac{1}{2}F : \tan \frac{1}{2}\theta;$$

$$\therefore \tan \frac{1}{2}\theta = \frac{gn}{R} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (91)$$

Also $OF : FC :: \sin \theta : \sin \phi$; but $\phi = (F - \theta)$;

then $r + \frac{1}{2}g = (R + \frac{1}{2}g) \frac{\sin \theta}{\sin (F - \theta)} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (92)$

$$BF = L = 2(R + \frac{1}{2}g) \sin \frac{1}{2}\theta. \quad \cdot \quad \cdot \quad \cdot \quad (93)$$

If the curvature of the main track is very sharp or the frog angle unusually small, F may be less than θ ; in which case the center O will be on the same side of the main track as C . Eq. 92 will become (by calling $r = -r$ and changing the signs)

$$(r - \frac{1}{2}g) = (R + \frac{1}{2}g) \frac{\sin \theta}{\sin (\theta - F)} \quad \cdot \quad \cdot \quad \cdot \quad (94)$$

If we call d the degree of curve corresponding to the radius r , and D the degree of curve corresponding to the radius R , also d' the degree of curve of a turnout from a straight track (the frog angle F being the same), it may be shown that $d = d' - D$ (very nearly). To illustrate we will take three cases, a number 6 frog (very blunt), a number 9 frog (very commonly used), and a number 12 frog (unusually sharp). Suppose $D = 4^\circ 0'$; also $D = 10^\circ 0'$; $g = 4' 8\frac{1}{2}'' = 4'.708$.

Frog number.	$D = 4^\circ$.				"L" for straight track.
	d	$d' - D$	Error.	L	
6	12° 54' 20''	12° 57' 52''	0° 03' 32''	56.57	56.50
9	8 30 27	8 31 04	0 0 37	84.85	84.75
12	0 18 33	0 18 36	0 0 03	112.72	113.00

Frog number.	$D = 10^\circ$				"L" for straight track.
	d	$d' - D$	Error.	L	
6	6° 53' 24''	6° 57' 52''	0° 04' 28''	56.66	56.50
9	2 27 54	2 28 56	0 01 02	84.86	84.75
12	5 44 26	5 46 24	0 01 58	112.91	113.00

A brief study of the above tabular form will show that the error involved in the use of the approximate rule for ordinary curves (4° or less) and for the usual frogs (about No. 9) is really insignificant, and that, even for sharper curves (10° or more), or for very blunt frogs, the error would never cause damage, considering the lower probable speed. In the most unfavorable case noted above the change in radius is about 1%. On account of the closeness of the approximation the method is frequently used. The remarkable agreement of the computed values of L with the corresponding values for a straight main track (the lead

somewhat greater than in the other, especially when the curvature of the main track is sharp. If the frog angle is also large, the curvature of the turnout is excessively sharp. If the frog angle is very small, the liability to derailment is great. Turnouts to the inside of a curved track should therefore be avoided, unless the curvature of the main track is small.

269. Double turnout from a straight track. In Fig. 143 the frogs F_l and F_r are generally made equal. Then, if there are

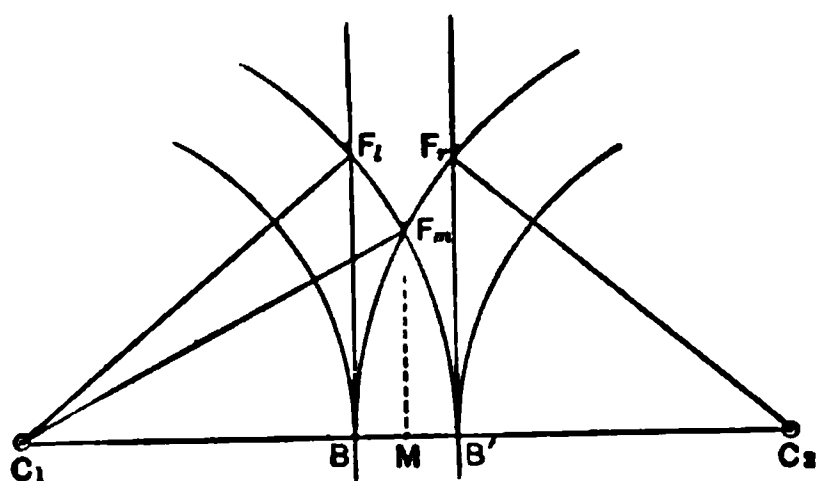


FIG. 143.

uniform curves from B' to F_l and from B to F_r , the required value of F_m is obtained from

$$\text{vers } \frac{1}{2}F_m = \frac{g}{2(r + \frac{1}{2}g)}, \quad . \quad . \quad . \quad . \quad (98)$$

r being found from Eq. 78, in which n is the frog number of F_l or F_r .

$$MF_m = r \tan \frac{1}{2}F_m;$$

but since $n_m = \frac{1}{2} \cot \frac{1}{2}F_m$,

$$MF_m = \frac{r}{2n_m}. \quad . \quad . \quad . \quad . \quad . \quad (99)$$

Since $\text{vers } F_l = \frac{g}{(r + \frac{1}{2}g)}$,

$$\text{vers } \frac{1}{2}F_m = \frac{1}{2} \text{vers } F_l, \quad . \quad . \quad . \quad . \quad . \quad (100)$$

Also, since $(C_1F_m)^2 = (MF_m)^2 + (C_1M)^2$, we have

$$(r + \frac{1}{2}g)^2 = \left(\frac{r}{2n_m}\right)^2 + r^2;$$

$$r^2 + rg + \frac{1}{4}g^2 = \frac{r^2}{4n_m^2} + r^2.$$

Simplifying and substituting $r = 2gn^2$, we have

$$2g^2n^2 + \frac{1}{4}g^2 = \frac{4g^2n^4}{4n_m^2};$$

$$n_m^2 = \frac{n^4}{2n^2 + \frac{1}{4}}.$$

Dropping the $\frac{1}{4}$, which is always insignificant in comparison with $2n^2$, we have

$$n_m = \frac{n}{\sqrt{2}} = n \times .707 \text{ (approx.)}. \quad . \quad . \quad (101)$$

Frogs are usually made with angles corresponding to integral values of n , or sometimes in "half" sizes, e.g. 6, $6\frac{1}{2}$, 7, $7\frac{1}{2}$, etc. If No. $8\frac{1}{2}$ frogs are used for F_i and F_r , the exact frog number for F_m is 6.01. This is so nearly 6 that a No. 6 frog may be used without sensible inaccuracy. Numbers 7 and 10 are a less perfect combination. If sharp frogs must be used, $8\frac{1}{2}$ and 12 form a very good combination.

If it becomes necessary to use other frogs because the right combination is unobtainable, it may be done by compounding the curve at the middle frog. F_i and F_r should be greater than $\frac{1}{2}F_m$. If equal to $\frac{1}{2}F_m$, the rails would be straight from the middle frog to the outer frogs. In Fig. 144, $\theta_1 = F_i - \frac{1}{2}F_m$. Drawing the chord $\overline{F_iF_m}$,

$$KF_iF_m = F_i - \frac{1}{2}\theta_1 = F_i - \frac{1}{2}F_i + \frac{1}{4}F_m = \frac{1}{2}(F_i + \frac{1}{2}F_m);$$

$$\overline{F_i F_m} = \frac{\overline{K F_m}}{\sin \overline{K F_i F_m}} = \frac{g}{2 \sin \frac{1}{2}(F_i + \frac{1}{2}F_m)}; \quad (102)$$

$$\overline{K F_i} = \overline{K F_m} \cot \overline{K F_i F_m} = \frac{1}{2}g \cot \frac{1}{2}(F_i + \frac{1}{2}F_m); \quad (103)$$

$$\begin{aligned} (r_i + \frac{1}{2}g) &= \frac{\overline{F_i F_m}}{2 \sin \frac{1}{2}\theta} = \frac{g}{4 \sin \frac{1}{2}(F_i + \frac{1}{2}F_m) \sin \frac{1}{2}(F_i - \frac{1}{2}F_m)} \\ &= \frac{\frac{1}{2}g}{\cos \frac{1}{2}F_m - \cos F_i} \quad (104) \end{aligned}$$

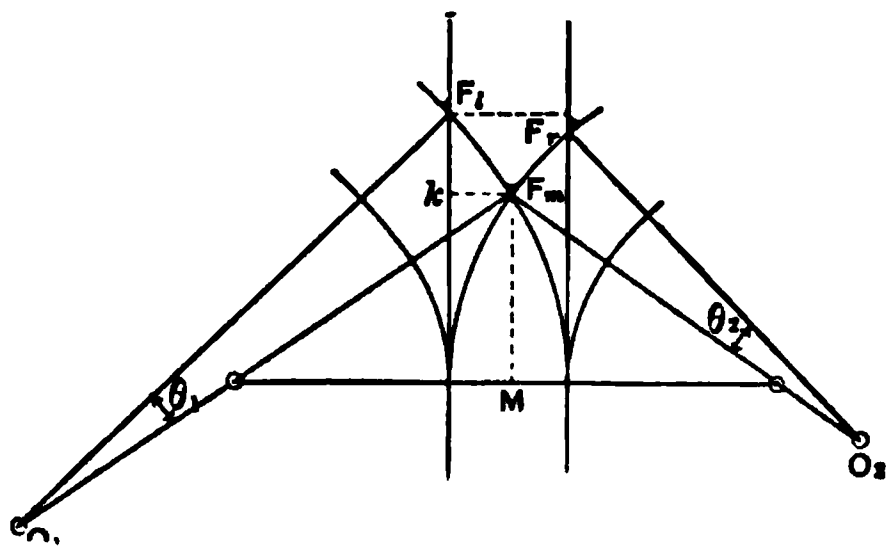


FIG. 144.

If three frogs, all different, *must* be used, the largest may be selected as F_m ; the radius of the lead rails may be found by an inversion of Eq. 98; F_m may be located in the center of the tracks by Eq. 99; then each of the smaller frogs may be located by separate applications of Eq. 102 or 103, the radius being determined by Eq. 104.

270. Two turnouts on the same side. In Fig. 145, let O_1 bisect $O_2 D$. Then $(r_i + \frac{1}{2}g) = \frac{1}{2}(r_i + \frac{1}{2}g)$; also, $O_1 O_2 = O_1 F_i$ and $F_r = F_i$.

$$\text{vers } F_m = \frac{g}{r_i + \frac{1}{2}g} = \frac{2g}{r_i + \frac{1}{2}g}; \quad (105)$$

$$BF_m = (r_i + \frac{1}{2}g) \sin F_m. \quad (106)$$

It may readily be shown that the relative values of F_r , F_i , and F_m are almost identical with those given in § 269; as may

be apparent when it is considered that the middle switch may be regarded simply as a curved main track, and that, as

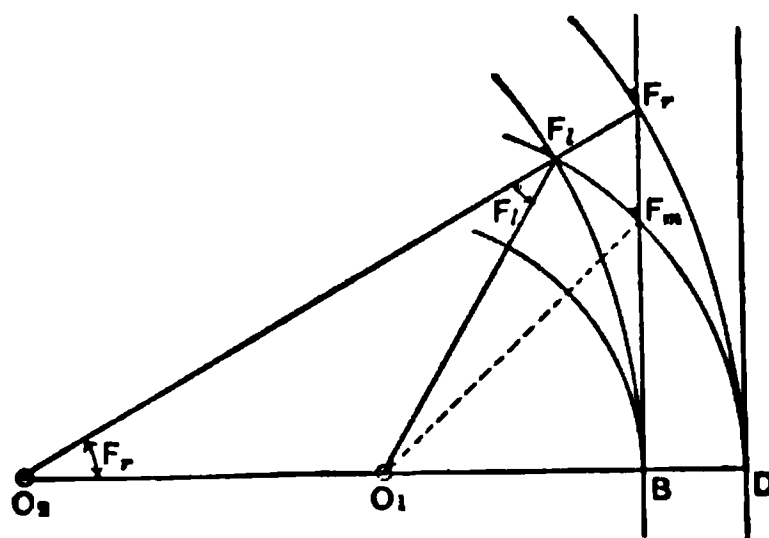


FIG. 145.

developed in § 267, the dimensions of turnouts are nearly the same whether the main track is straight or slightly curved.

271. Connecting curve from a straight track. The “connecting curve” is the track lying

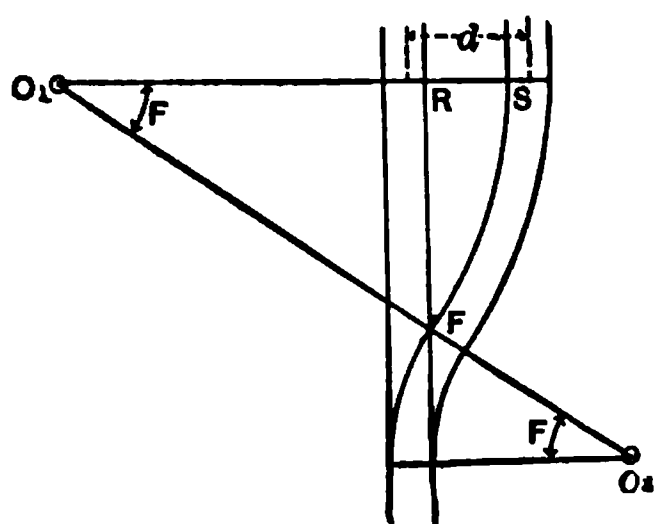


FIG. 146.

between the frog and the side track where it becomes parallel to the main track (FS in Fig. 146 or 147). Call d the distance between track centers. The angle $FO_1R = F$ (see Fig. 146). Call r' the radius of the connecting curve. Then

$$(r' - \frac{1}{2}g) = \frac{d - g}{\text{vers } F}; \quad . \quad . \quad . \quad . \quad . \quad (107)$$

$$FR = (r' - \frac{1}{2}g) \sin F. \quad . \quad . \quad (108)$$

If it is considered that the distance FR consumes too much track room, it may be shortened by the method indicated in Fig. 151.

272. Connecting curve from a curved track to the OUTSIDE. When the main track is curved, the required quantities are the radius r of the connecting curve from F to S , Fig. 147, and its length or central angle. In the triangle CSF

$$CS + CF : CS - CF :: \tan \frac{1}{2}(CFS + CSF) : \tan \frac{1}{2}(CFS - CSF);$$

but $\frac{1}{2}(CFS + CSF) = 90 - \frac{1}{2}\psi$; and, since the triangle O_1SF is isosceles, $\frac{1}{2}(CFS - CSF) = \frac{1}{2}F$;

$$\begin{aligned} \therefore 2R + d : d - g &:: \cot \frac{1}{2}\psi : \tan \frac{1}{2}F \\ &:: \cot \frac{1}{2}F : \tan \frac{1}{2}\psi; \end{aligned}$$

$$\therefore \tan \frac{1}{2}\psi = \frac{2n(d - g)}{2R + d} \quad \dots \dots \dots (109)$$

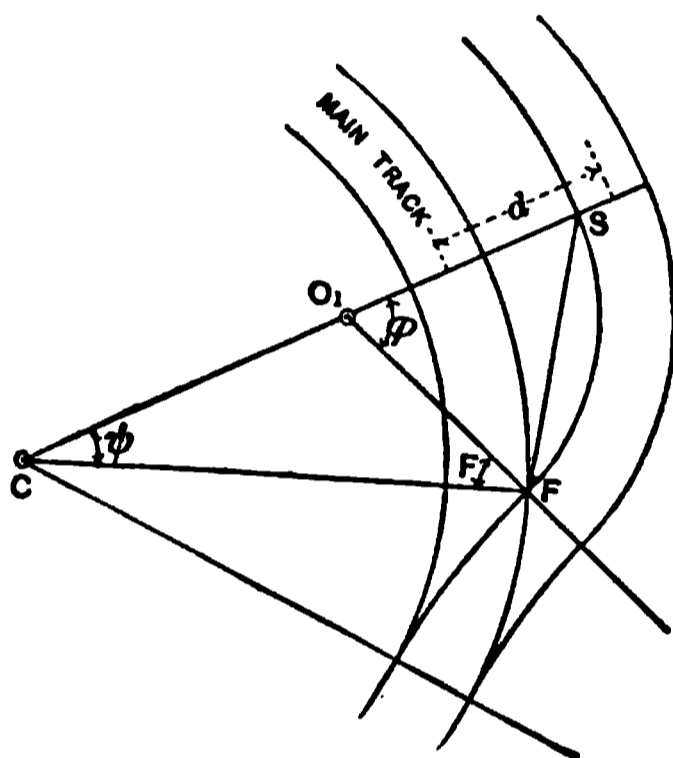


FIG. 147.

From the triangle CO_1F we may derive

$$\begin{aligned} r - \frac{1}{2}g : R + \frac{1}{2}g &:: \sin \psi : \sin (F + \psi); \\ r - \frac{1}{2}g &= (R + \frac{1}{2}g) \frac{\sin \psi}{\sin (F + \psi)} \quad \dots \dots \dots (110) \end{aligned}$$

Also $FS = 2(r - \frac{1}{2}g) \sin \frac{1}{2}(F + \psi). \quad \dots \dots \dots (111)$

273. Connecting curve from a curved track to the INSIDE.
As above, it may readily be deduced from the triangle CFS (see Fig. 148) that

$$(2R - d) : (d - g) :: \cot \frac{1}{2}\psi : \tan \frac{1}{2}F,$$

and finally that

$$\tan \frac{1}{2}\psi = \frac{2n(d - g)}{2R - d} \quad \dots \dots \dots (112)$$

the same as Eq. 112, but

$$r + \frac{1}{2}g = (R - \frac{1}{2}g) \frac{\sin \psi}{\sin (\psi - F)}. \quad . \quad . \quad (116)$$

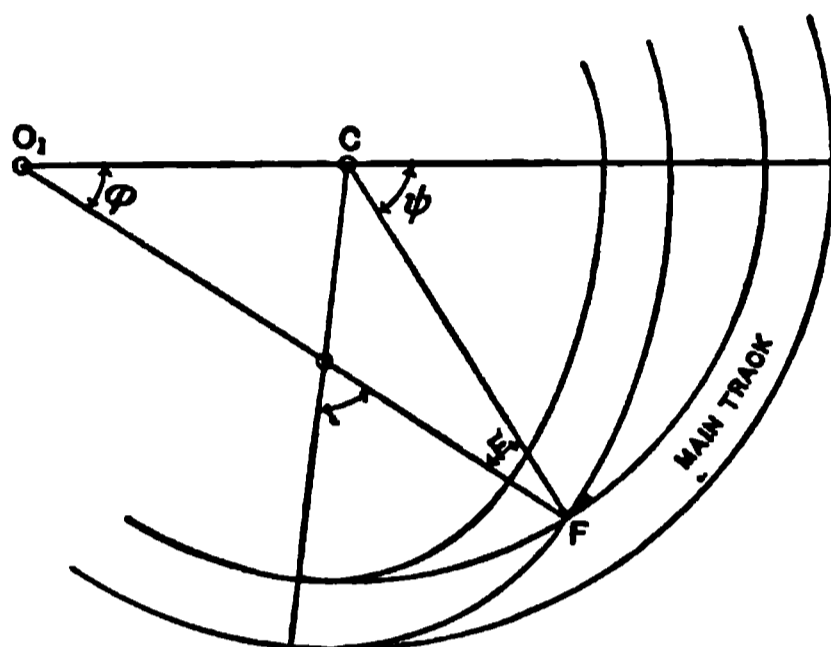


FIG. 150.

274. Crossover between two parallel straight tracks. (See Fig. 151.) The turnouts are as usual. The crossover track may be straight, as shown by the full lines, or it may be a reversed curve, as shown by the dotted lines. The reversed curve shortens the total length of track required, but is somewhat objectionable. The first method requires that both frogs must be equal. The second method permits unequal frogs, although equal frogs are preferable. The length of straight crossover track is F_1T .

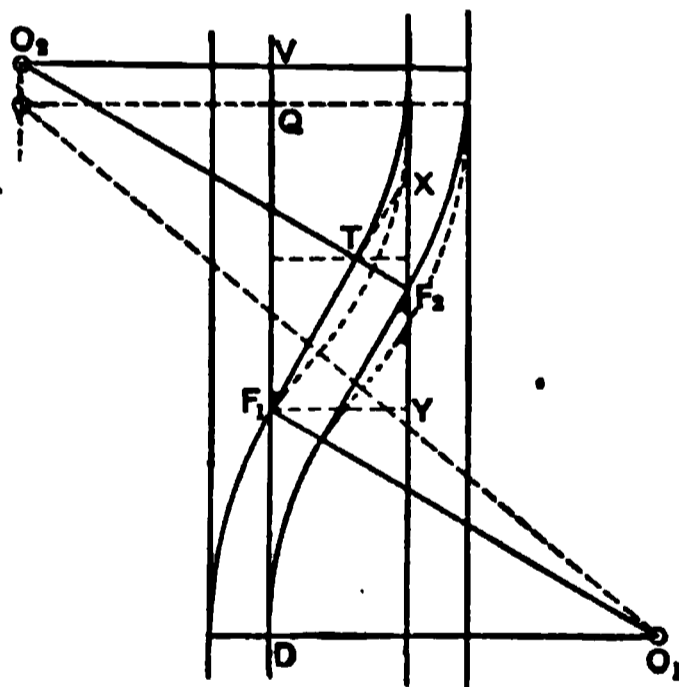


FIG. 151.

$$F_1T \sin F_1 + g \cos F_1 = d - g;$$

$$F_1T = \frac{d - g}{\sin F_1} - g \cot F_1. \quad . \quad . \quad . \quad . \quad (117)$$

The total distance along the track may be derived as follows:

$$DV = 2DF_1 + F_1Y = 2DF_1 + XY - XF_1;$$

$$XY = (d - g) \cot F_1; \quad XF_1 = g \div \sin F_1;$$

$$\therefore DV = 2DF_1 + (d - g) \cot F_1 - \frac{g}{\sin F_1}. \quad (118)$$

If a reversed curve with equal frogs is used, we have

$$\text{vers } \theta = \frac{d}{2r}; \quad (119)$$

also

$$DQ = 2r \sin \theta. \quad (120)$$

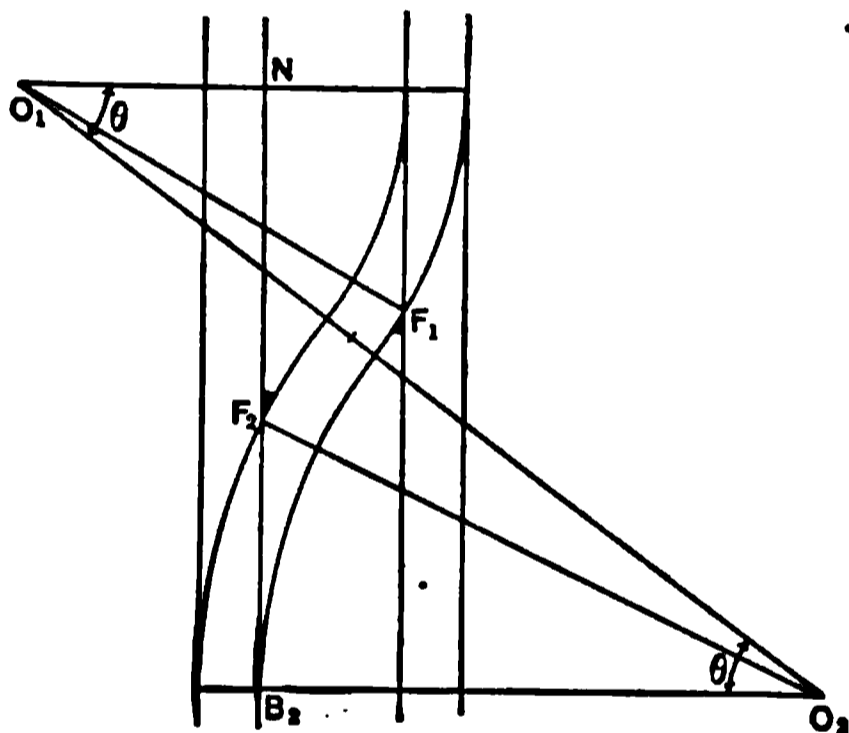


FIG. 152.

If the frogs are unequal, we will have (see Fig. 152)

$$r_2 \text{ vers } \theta + r_1 \text{ vers } \theta = d;$$

$$\therefore \text{vers } \theta = \frac{d}{r_1 + r_2}; \quad (121)$$

also the distance along the track

$$B_2N = (r_1 + r_2) \sin \theta. \quad (122)$$

275. Crossover between two parallel curved tracks. (a) Using a straight connecting curve. This solution has limitations. If one frog (F_1) is chosen, F_2 becomes determined, being a function of F_1 . If F_1 is less than some limit, depending on the width

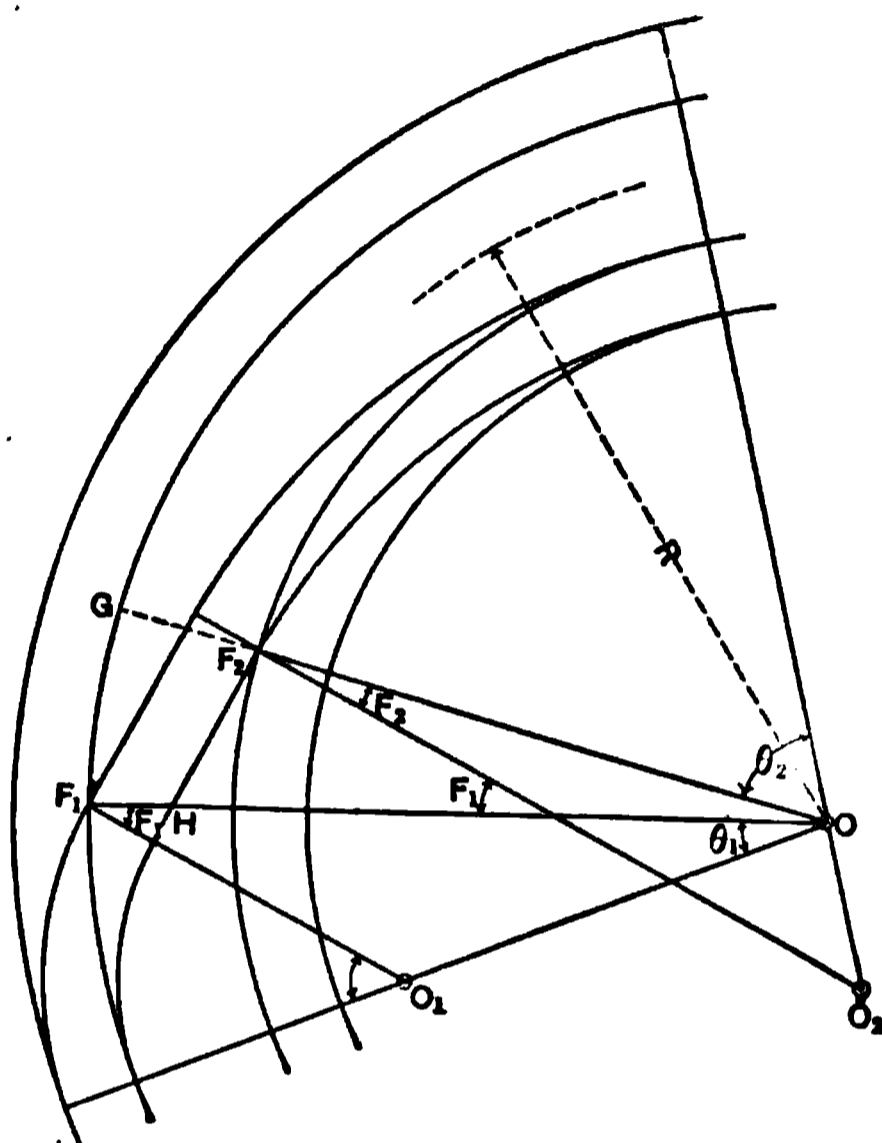


FIG. 153.

(*d*) between the parallel tracks, this solution becomes impossible. In Fig. 153 assume F_1 as known. Then $F_1H = g \sec F_1$. In the triangle $HO F_2$, we have

$$\sin HF_2O : \sin F_2HO :: HO : F_2O;$$

$$\sin F_2HO = \cos F_1; \quad HF_2O = 90^\circ + F_1;$$

$$\therefore \sin HF_2O = \cos F_1.$$

$$HO = R + \frac{1}{2}d - \frac{1}{2}g - g \sec F_1; \quad F_2O = R - \frac{1}{2}d + \frac{1}{2}g;$$

$$\therefore \cos F_2 = \cos F_1 \frac{R + \frac{1}{2}d - \frac{1}{2}g - g \sec F_1}{R - \frac{1}{2}d + \frac{1}{2}g}. \quad (123)$$

Knowing F_1 , θ_1 is determinable from Eq. 91. Fig. 153 shows the case where θ_1 is greater than F_1 . Fig. 154 shows the case where it is less. The demonstration of Eq. 123 is applicable to

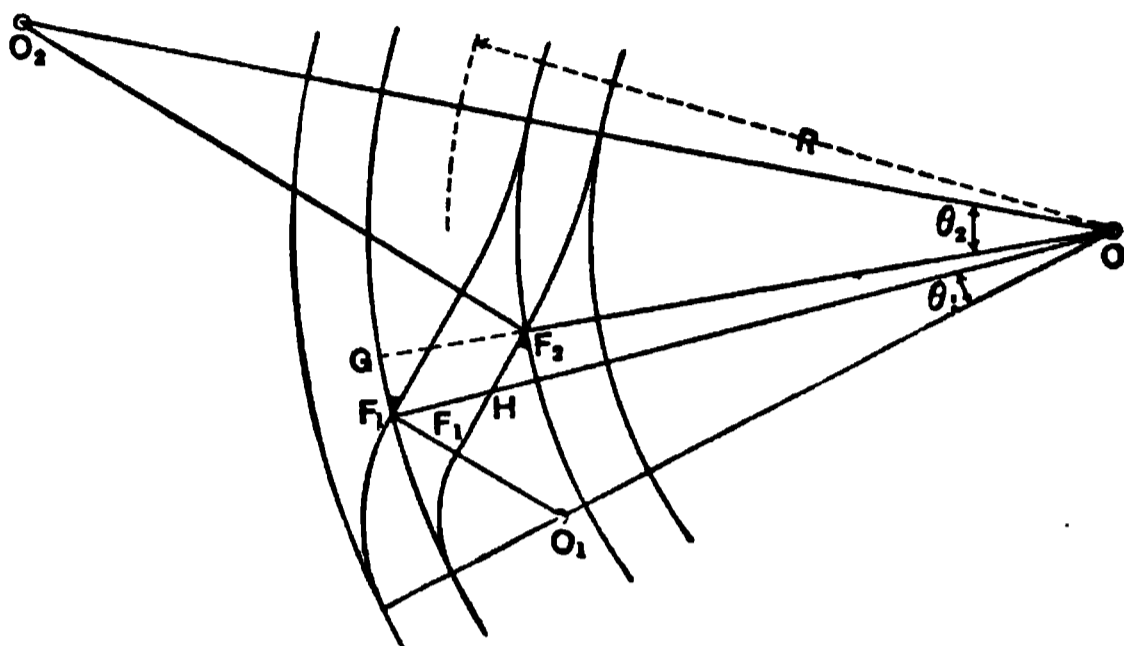


FIG. 154.

both figures. The relative position of the frogs F_1 and F_2 may be determined as follows, the solution being applicable to both Figs. 153 and 154:

$$\angle HOF_2 = 180^\circ - (90^\circ - F_1) - (90^\circ + F_2) = F_1 - F_2.$$

Then

$$GF_1 = 2(R + \frac{1}{2}d - \frac{1}{2}g) \sin \frac{1}{2}(F_1 - F_2). \quad (124)$$

Since F_1 comes out *any* angle, its value will not be in general that of an even frog number, and it will therefore need to be made to order.

(b) Continuing the switch-rail curves until they meet as a reversed curve. In this case F_1 and F_2 may be chosen at pleasure (within limitations), and they will of course be of regular sizes and equal or unequal as desired. F_1 and F_2 being known, θ_1 and θ_2 are computed by Eq. 95 and 91. In the triangle OO_1O_2 (see Fig. 155)

$$\text{vers } \psi = \frac{2(S - OO_1)(S - OO_2)}{OO_1 - OO_2},$$

in which

$$S = \frac{1}{2}(OO_1 + OO_2 + O_1O_2);$$

Although the above method introduces a reversed curve, yet it uses up less track than the first method and permits the use of ordinary frogs rather than those having some special angle which must be made to order.

276. Practical rules for switch-laying. A consideration of the previous sections will show that the formulæ are comparatively simple when the lead rails are assumed as circular; that they become complicated, even for turnouts from a straight main track, when the effect of straight frog and point rails is allowed for, and that they become hopelessly complicated when allowing for this effect on turnouts from a curved main track. It is also shown (§ 267) that the length of the lead is practically

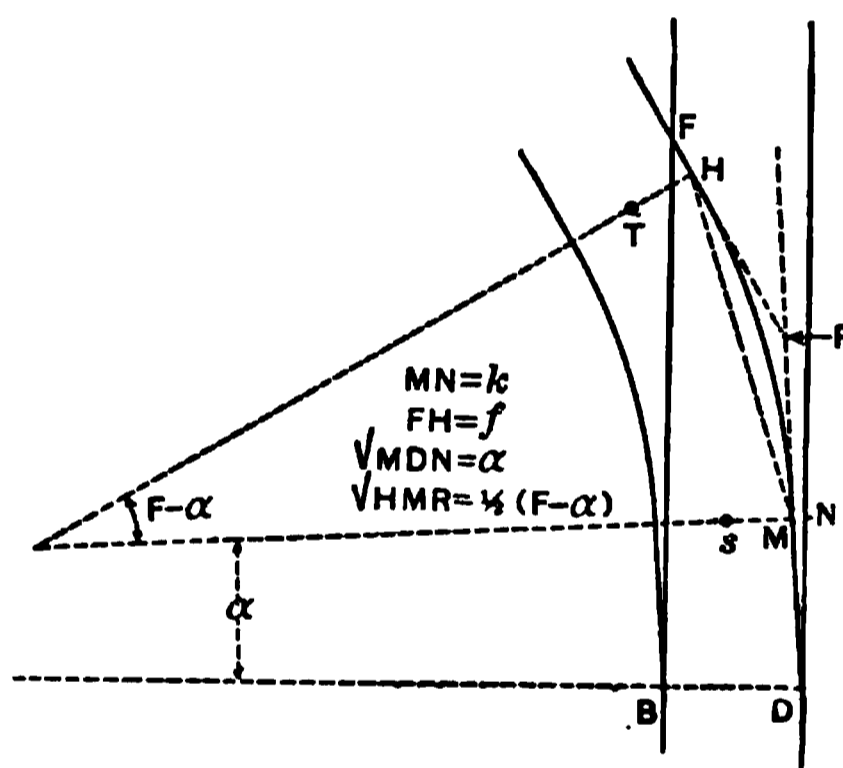


FIG. 140.

the same whether the main track is straight or is curved with such curves as are commonly used, and that the degree of curve of the lead rails from a curved main track may be found with close approximation by mere addition or subtraction. From this it may be assumed that, if the length of lead (L) and the radius of the lead rails (r) are computed from Eq. 87 and 90 for various frog angles, the same leads may be used for curved main track; also, that the degree of curve of the lead rails may be found by addition or subtraction, as indicated in § 267, and that the approximations involved will not be of practical detriment.

In accordance with this plan Table III has been computed from Eq. 87, 88, and 90. The *leads* there given may be used for all main tracks straight or curved. The table gives the degree of curve of the lead rails for *straight* main track; for a turnout to the *inside*, *add* the degree of curve of the main track; for a turnout to the *outside*, *subtract* it.

If the position of the switch-block is definitely determined, then the rails must be cut accordingly; but when some freedom is allowable (which never need exceed 15 feet and may require but a few inches), one rail-cutting may be avoided. Mark on the rails at *B*, *F*, and *D*; measure off the length of the switch-rails *DN*; offset $\frac{1}{2}g + k$ from *N* for the point *S*. The point *H* may be located (temporarily) by measuring along the rail a distance *FH* ($= f$) and then swinging out a distance of $f \div n$ (*n* being the frog number). $HT = \frac{1}{2}g$ and is measured at right angles to *FH*. Points for track centers between *S* and *T* may be laid off by a transit or by the use of a string and tape. Substituting in Eq. 31 the value of *R* and of *chord* ($= ST$), we may compute *x* ($= db$). Locate the middle point *d* and the quarter points *a''* and *c''*. Then *a''a* and *c''c* each equal three-fourths of *db*. Theoretically this gives a parabola rather than a circle, but the difference for all practical cases is too small for measurement.

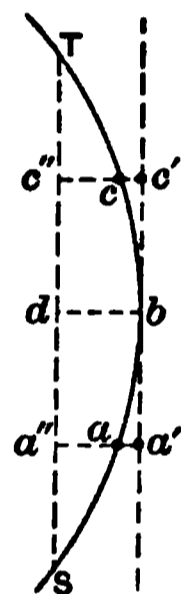


FIG. 156.

Example. Given a main track on a 4° curve; a turnout to the outside, using a number 9 frog; gauge $4' 8\frac{1}{2}''$; $f = 3'.37$; $k = 5\frac{1}{2}''$; $DN = 15' 0''$ and $\alpha = 1^\circ 50'$. Then for a *straight* track *r* would equal 681.16 [$d = 8^\circ 25'$]. For this curved track *d* will be nearly $(8^\circ 25' - 4^\circ) = 4^\circ 25'$, or *r* will be 1297.6. *L* for the *straight* track would be 72.20; but since the lead is slightly increased (see § 267) when the turnout is on the outside of a curve, *L* may here be called 72.5. $FH = f = 3'.37$; $f \div n = 3.37 \div 9 = 0'.375 = 4''.5$. *H*, *T*, and *S* may be located as described above. *ST* may be measured on the ground, or it may be computed from Eq. 88, giving the value

of 53.80 feet for straight track. Since it is slightly more for a turnout to the outside of a curve, it may be called 54.0. Then

$x = db = \frac{(54.0)^2}{8 \times 1297.6} = 0.281$ feet, and aa'' and $cc'' = 0.21$ foot.

CROSSINGS.

277. Two straight tracks. When two straight tracks cross each other, four frogs are necessary, the angles of two of them being supplementary to the angles of the other. Since such crossings are sometimes operated at high speeds, they should be

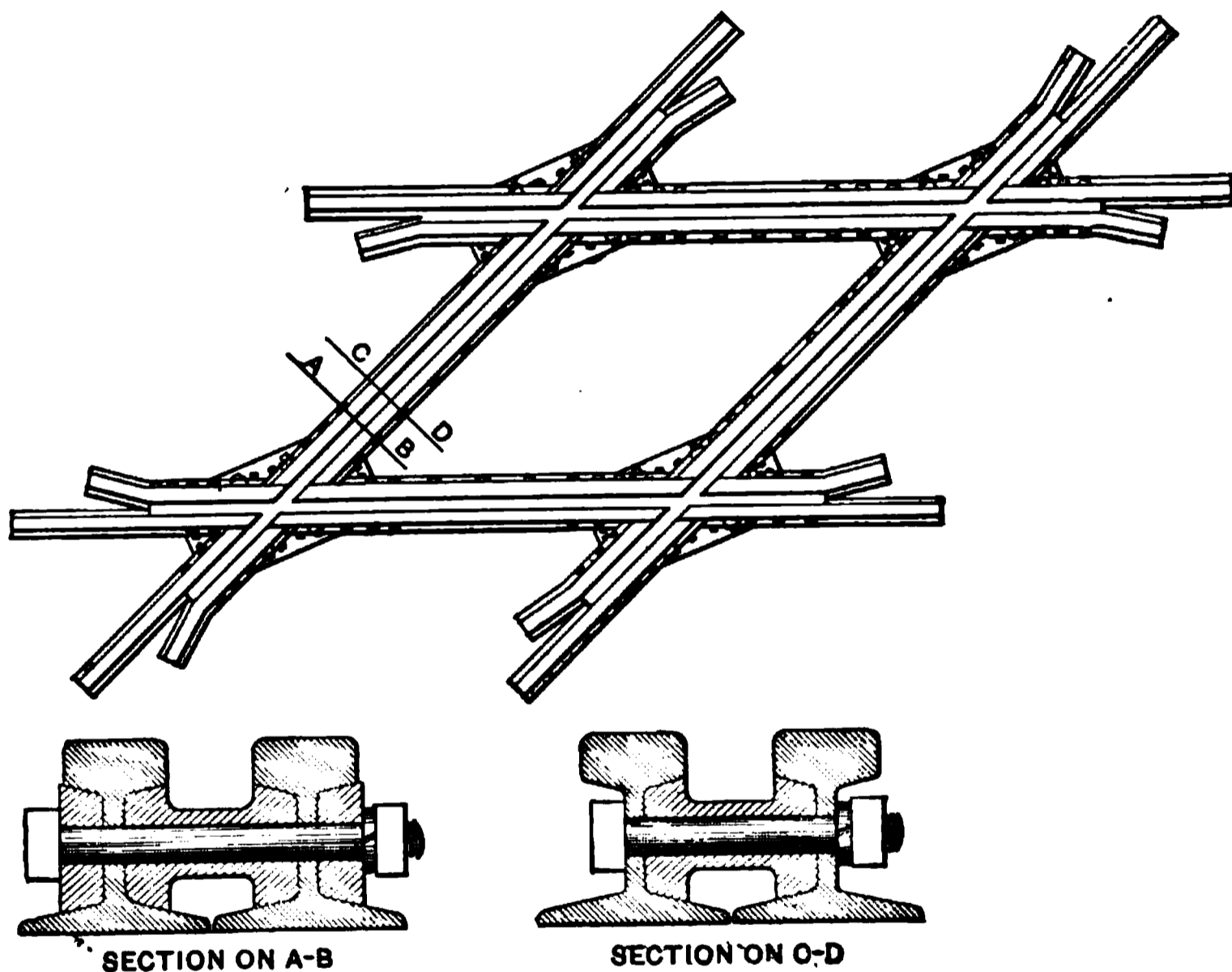


FIG. 157.—CROSSING.

very strongly constructed, and the angles should preferably be 90° or as near that as possible. The frogs will not in general be “stock” frogs of an even number, especially if the angles are large, but must be made to order with the required angles as measured. In Fig. 157 are shown the details of such a crossing. Note the fillers, bolts, and guard-rails.

278. One straight and one curved track. Structurally the crossing is about the same as above, but the frog angles are all unequal. In Fig. 158, R is known, and the angle M , made by the center lines of the tracks at their point of intersection, is also known.

$$M = NCM. \quad NC = R \cos M.$$

$$\left. \begin{aligned} (R - \tfrac{1}{2}g) \cos F_1 &= NC + \tfrac{1}{2}g; \\ \therefore \cos F_1 &= \frac{R \cos M + \tfrac{1}{2}g}{R - \tfrac{1}{2}g}. \\ \text{Similarly } \cos F_2 &= \frac{R \cos M + \tfrac{1}{2}g}{R + \tfrac{1}{2}g}, \\ \cos F_3 &= \frac{R \cos M - \tfrac{1}{2}g}{R + \tfrac{1}{2}g}, \\ \cos F_4 &= \frac{R \cos M - \tfrac{1}{2}g}{R - \tfrac{1}{2}g}. \end{aligned} \right\} (129)$$

FIG. 158.

279. Two curved tracks. The four frogs are unequal, and the angle of each must be computed. The radii R_1 and R_2 are

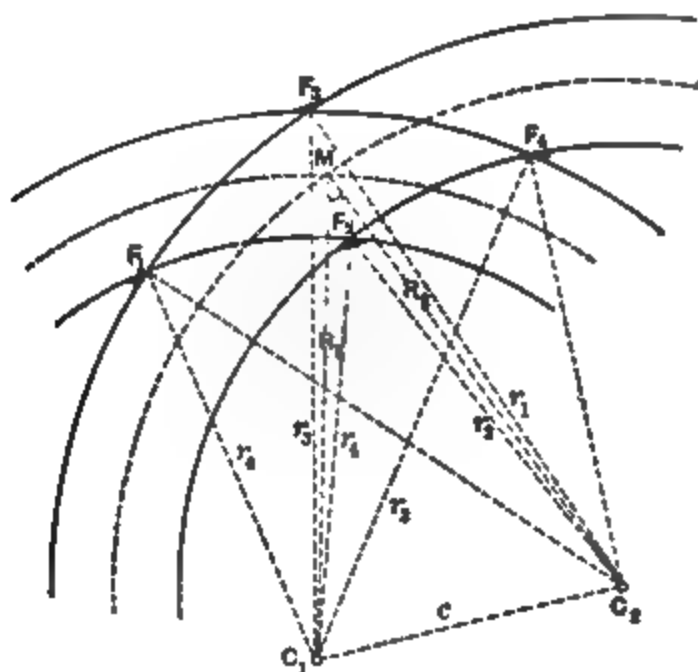


FIG. 159.

known; also the angle M . r_1 , r_2 , r_3 , and r_4 are therefore known by adding or subtracting $\tfrac{1}{2}g$, but the lines are so indi-

cated for brevity. Call the angle $MC_1C_2 = C_1$, the angle $MC_2C_1 = C_2$, and the line $C_1C_2 = c$. Then

$$\frac{1}{2}(C_1 + C_2) = 90^\circ - \frac{1}{2}M$$

and

$$\tan \frac{1}{2}(C_1 - C_2) = \cot \frac{1}{2}M \frac{R_2 - R_1}{R_2 + R_1}.$$

C_1 and C_2 then become known and

$$c = C_1C_2 = R_1 \frac{\sin M}{\sin C_1}.$$

In the triangle $F_1C_1C_2$, call $\frac{1}{2}(c + r_1 + r_2) = s_1$; then

$$\text{Similarly} \quad \left. \begin{aligned} \text{vers } F_1 &= \frac{2(s_1 - r_1)(s_1 - r_2)}{r_1 r_2}, \\ \text{vers } F_2 &= \frac{2(s_2 - r_1)(s_2 - r_2)}{r_1 r_2}, \\ \text{vers } F_3 &= \frac{2(s_3 - r_1)(s_3 - r_2)}{r_1 r_2}, \\ \text{vers } F_4 &= \frac{2(s_4 - r_1)(s_4 - r_2)}{r_1 r_2}. \end{aligned} \right\} \quad . \quad . \quad (130)$$

In the above equations

$$s_1 = \frac{1}{2}(c + r_1 + r_2),$$

$$s_2 = \frac{1}{2}(c + r_1 + r_3),$$

$$s_3 = \frac{1}{2}(c + r_2 + r_3).$$

APPENDIX.

THE ADJUSTMENTS OF INSTRUMENTS.

THE accuracy of instrumental work may be vitiated by any one of a large number of inaccuracies in the geometrical relations of the parts of the instruments. Some of these relations are so apt to be altered by ordinary usage of the instrument that the makers have provided adjusting-screws so that the inaccuracies may be readily corrected. There are other possible defects, which, however, will seldom be found to exist, provided the instrument was properly made and has never been subjected to treatment sufficiently rough to distort it. Such defects, when found, can only be corrected by a competent instrument maker or repairer.

A WARNING is necessary to those who would test the accuracy of instruments, and especially to those whose experience in such work is small. Lack of skill in handling an instrument will often indicate an apparent error of adjustment when the real error is very different or perhaps non-existent. It is always a safe plan when testing an adjustment to note the amount of the apparent error; then, beginning anew, make another independent determination of the amount of the error. When two or more *perfectly independent* determinations of such an error are made it will generally be found that they differ by an appreciable amount. The *differences* may be due in variable measure to careless inaccurate manipulation and to instrumental *defects* which are wholly independent of the particular test being made. Such careful determinations of the amounts of the errors are generally advisable in view of the next paragraph.

DO NOT DISTURB THE ADJUSTING-SCREWS ANY MORE THAN NECESSARY. Although metals are apparently rigid, they are really elastic and yielding. If some parts of a complicated mechanism, which is held together largely by friction, are subjected to greater internal stresses than other parts of the mechanism, the jarring resulting from handling will frequently cause a slight readjustment in the parts which will tend to more nearly equalize the internal stresses. Such action frequently occurs with the adjusting mechanism of instruments. One screw may be strained more than others. The friction of parts may prevent the opposing screw from *immediately* taking up an equal stress. Perhaps the adjustment appears perfect under these conditions. Jarring diminishes the friction between the parts, and the unequal stresses tend to equalize. A motion takes place which, although microscopically minute, is sufficient to indicate an error of adjustment. A readjustment, made by unskillful hands, may not make the final adjustment any more perfect. The frequent shifting of adjusting-screws wears them badly, and when the screws are worn it is still more difficult to keep them from moving enough to vitiate the adjustments. It is therefore preferable in many cases to refrain from disturbing the adjusting-screws, especially as the accuracy of the work done is not *necessarily* affected by errors of adjustment, as may be illustrated :

(a) Certain operations are *absolutely* unaffected by certain errors of adjustment.

(b) Certain operations are so slightly affected by certain *small* errors of adjustment that their effect may properly be neglected.

(c) Certain errors of adjustment may be readily allowed for and neutralized so that no error results from the use of the unadjusted instrument. Illustrations of all these cases will be given under their proper heads.

ADJUSTMENTS OF THE TRANSIT.

1. *To have the plate-bubbles in the center of the tubes when the axis is vertical.* Clamp the upper plate and, with the lower

clamp loose, swing the instrument so that the plate-bubbles are parallel to the lines of opposite leveling-screws. Level up until both bubbles are central. Swing the instrument 180° . If the bubbles again settle at the center, the adjustment is perfect. If either bubble does not settle in the center, move the leveling-screws until the bubble is *half-way* back to the center. Then, before touching the adjusting-screws, note carefully the position of the bubbles and observe whether the bubbles always settle at the *same* place in the tube, no matter to what position the instrument may be rotated. When the instrument is so leveled, the axis is truly vertical and the discrepancies between this constant position of the bubbles and the centers of the tubes measure the errors of adjustment. By means of the adjusting-screws bring each bubble to the center of the tube. If this is done so skillfully that the true level of the instrument is not disturbed, the bubbles should settle in the center for all positions of the instrument. Under unskillful hands, two or more such trials may be necessary.

When the plates are not horizontal, the measured angle is greater than the true horizontal angle by the difference between the measured angle and its projection on a horizontal plane. When this angle of inclination is small, the difference is insignificant. Therefore when the plate-bubbles are *very nearly* in adjustment, the error of measurement of horizontal angles may be far within the lowest unit of measurement used. A *small* error of adjustment of the plate-bubble *perpendicular* to the telescope will affect the horizontal angles by only a small proportion of the error, which will be perhaps imperceptible. Vertical angles will be affected by the same insignificant amount. A *small* error of adjustment of the plate-bubble *parallel* to the telescope will affect horizontal angles very slightly, but will affect vertical angles by the full amount of the error.

All error due to unadjusted plate-bubbles may be avoided by noting in what positions in the tubes the bubbles will remain fixed for all positions of azimuth and then keeping the bubbles adjusted to these positions, for the axis is then truly vertical. It will often save time to work in this way temporarily rather than to stop to make the adjustments. This should especially be done when accurate vertical angles are required.

When the bubbles are truly adjusted, they should remain stationary, regardless of whether the telescope is revolved with the upper plate loose and the lower plate clamped or whether the whole instrument is revolved, the plates being clamped together. If there is any appreciable difference,

it shows that the two vertical axes or "centers" of the plates are not concentric. This may be due to cheap and faulty construction or to the excessive wear that may be sometimes observed in an old instrument originally well made. In either case it can only be corrected by a maker.

2. *To make the revolving axis of the telescope perpendicular to the vertical axis of the instrument.* This is best tested by using a long plumb-line, so placed that the telescope must be pointed upward at an angle of about 45° to sight at the top of the plumb-line and downward about the same amount, if possible, to sight at the lower end. The vertical axis of the transit must be made truly vertical. Sight at the upper part of the line, clamping the horizontal plates. Swing the telescope down and see if the cross-wire again bisects the cord. If so, the adjustment is *probably* perfect (a conceivable exception will be noted later); if not, raise or lower one end of the axis by means of the adjusting-screws, placed at the top of one of the standards, until the cross-wire will bisect the cord both at top and bottom. The plumb-bob may be steadied, if necessary, by hanging it in a pail of water. As many telescopes cannot be focused on an object nearer than 6 or 8 feet from the telescope, this method requires a long plumb-line swung from a high point, which may be inconvenient.

Another method is to set up the instrument about 10 feet from a high wall. After leveling, sight at some convenient mark high up on the wall. Swing the telescope down and make a mark (when working alone some convenient natural mark may generally be found) low down on the wall. Plunge the telescope and revolve the instrument about its vertical axis and again sight at the upper mark. Swing down to the lower mark. If the wire again bisects it, the adjustment is perfect. If not, fix a point *half-way* between the two positions of the lower mark. The plane of this point, the upper point, and the center of the instrument is truly vertical. Adjust the axis to these upper and lower points as when using the plumb-line.

3. *To make the line of collimation perpendicular to the revolving axis of the telescope* With the instrument level and

the telescope nearly horizontal point at some well-defined point at a distance of 200 feet or more. Plunge the telescope and establish a point in the opposite direction. Turn the whole instrument about the vertical axis until it again points at the first mark. Again plunge to "direct position" (i.e., with the level-tube *under* the telescope). If the vertical cross-wire again points at the second mark, the adjustment is perfect. If not, the error is *one-fourth* of the distance between the two positions of the second mark. Loosen the capstan-screw on one side of the telescope and tighten it on the other side until the vertical wire is set at the one-fourth mark. Turn the whole instrument by means of the tangent screw until the vertical wire is *midway* between the two positions of the second mark. Plunge the telescope. If the adjusting has been skillfully done, the cross-wire should come exactly to the first mark. As an "erecting eyepiece" reinverts an image already inverted, the ring carrying the cross-wires must be moved in the *same* direction as the *apparent* error in order to correct that error.

The necessity for the third adjustment lies principally in the practice of producing a line by plunging the telescope, but when this is required to be done with great accuracy it is always better to obtain the forward point by reversion (as described above for making the test) and take the *mean* of the two forward points. Horizontal and vertical angles are practically unaffected by *small* errors of this adjustment, unless, in the case of horizontal angles, the vertical angles to the points observed are very different.

Unnecessary motion of the adjusting-screws may sometimes be avoided by carefully establishing the forward point on line by repeated reversions of the instrument, and thus determining by repeated trials the exact amount of the error. *Differences* in the amount of error determined would be evidence of inaccuracy in manipulating the instrument, and would show that an adjustment based on the first trial would *probably* prove unsatisfactory.

The 2d and 3d adjustments are mutually dependent. If either adjustment is badly out, the other adjustment cannot be made except as follows :

(a) The second adjustment can be made regardless of the third when the lines to the high point and the low point make *equal* angles with the horizontal.

(b) The third adjustment can be made regardless of the second when the front and rear points are *on a level* with the instrument.

When both of these requirements are *nearly* fulfilled, and especially when the error of either adjustment is small, no trouble will be found in perfecting either adjustment on account of a small error in the other adjustment.

If the test for the second adjustment is made by means of the plumb-line and the vertical cross-wire intersects the line at all points as the telescope is raised or lowered, it not only demonstrates at once the accuracy of that adjustment, but also shows that the third adjustment is either perfect or has so small an error that it does not affect the second.

4. *To have the bubble of the telescope-level in the center of the tube when the line of collimation is horizontal.* The line of collimation should coincide with the optical axis of the telescope. If the object-glass and eyepiece have been properly centered, the previous adjustment will have brought the vertical cross-wire to the center of the field of view. The horizontal cross-wire should also be brought to the center of the field of view, and the bubble should be adjusted to it.

a. Peg method. Set up the transit at one end of a nearly level stretch of about 300 feet. Clamp the telescope with its bubble in the center. Drive a stake vertically under the eyepiece of the transit, and another about 300 feet away. Observe the height of the center of the eyepiece (the telescope being level) above the stake (calling it a); observe the reading of the rod when held on the other stake (calling it b); take the instrument to the other stake and set it up so that the eyepiece is vertically over the stake, observing the height, c ; take a reading on the first stake, calling it d . If this adjustment is perfect, then

$$a - d = b - c,$$

$$\text{or} \quad (a - d) - (b - c) = 0.$$

$$\text{Call} \quad (a - d) - (b - c) = 2m.$$

When m is positive, the line points downward;

“ m “ negative, “ “ “ upward.

To adjust: if the line points *up*, sight the horizontal cross-wire (by moving the vertical tangent screw) at a point which is *m* lower, then adjust the bubble so that it is in the center.

By taking several independent values for *a*, *b*, *c*, and *d*, a mean value for *m* is obtained, which is more reliable and which may save much unnecessary working of the adjusting-screws.

b. Using an auxiliary level. When a carefully adjusted level is at hand, this adjustment may sometimes be more easily made by setting up the transit and level, so that their lines of collimation are as nearly as possible at the same height. If a point may be found which is half a mile or more away and which is on the horizontal cross-wire of the level, the horizontal cross-wire of the transit may be pointed directly at it, and the bubble adjusted accordingly. Any slight difference in the heights of the lines of collimation of the transit and level (say $\frac{1}{4}$ ") may almost be disregarded at a distance of $\frac{1}{2}$ mile or more, or, if the difference of level would have an appreciable effect, even this may be practically eliminated by making an estimated allowance when sighting at the distant point. Or, if a distant point is not available, a level-rod with target may be used at a distance of (say) 300 feet, making allowance for the carefully determined difference of elevation of the two lines of collimation.

5. *Zero of vertical circle.* When the line of collimation is truly horizontal and the vertical axis is truly vertical, the reading of the vertical circle should be 0° . If the arc is adjustable, it should be brought to 0° . If it is not adjustable, the *index error* should be observed, so that it may be applied to all readings of vertical angles.

ADJUSTMENTS OF THE WYE LEVEL.

1. *To make the line of collimation coincide with the center of the rings.* Point the intersection of the cross-wires at some well-defined point which is at a considerable distance. The instrument need not be level, which allows much greater liberty in choosing a convenient point. The vertical axis should be

clamped, and the clips over the wyes should be loosened and raised. Rotate the telescope in the wyes. The intersection of the cross-wires should be continually on the point. If it is not, it requires adjustment. Rotate the telescope 180° and adjust *one-half* of the error by means of the capstan-headed screws that move the cross-wire ring. It should be remembered that, with an erecting telescope, on account of the inversion of the image, the ring should be moved in the direction of the *apparent* error. Adjust the other half of the error with the leveling-screws. Then rotate the telescope 90° from its usual position, sight accurately at the point, and then rotate 180° from that position and adjust any error as before. It may require several trials, but it is necessary to adjust the ring until the intersection of the cross-wires will remain on the point for any position of rotation.

If such a test is made on a very distant point and again on a point only 10 or 15 feet from the instrument, the adjustment may be found correct for one point and incorrect for the other. This indicates that the object-slide is improperly centered. Usually this defect can only be corrected by an instrument-maker. If the difference is very small it may be ignored, but the adjustment should then be made on a point which is at about the mean distance for usual practice—say 150 feet.

If the whole image appears to shift as the telescope is rotated, it indicates that the eyepiece is improperly adjusted. This defect is likewise usually corrected only by the maker. It does not interfere with instrumental accuracy, but it usually causes the intersection of the cross-wires to be eccentric with the field of view.

2. *To make the axis of the level tube parallel to the line of collimation.* Raise the clips as far as possible. Swing the level so that it is parallel to a pair of opposite leveling-screws and clamp it. Bring the bubble to the middle of the tube by means of the leveling-screws. Take the telescope out of the wyes and replace it end for end, using *extreme care* that the wyes are not jarred by the action. If the bubble does not come to the center, correct *one-half* of the error by the vertical adjusting-screws at one end of the bubble. Correct the other half by the leveling-screws. Test the work by again changing the telescope end for end in the wyes.

Care should be taken while making this adjustment to see that the level-tube is vertically under the telescope. With the bubble in the center of the tube, rotate the telescope in the wyes for a considerable angle each side of the vertical. If the first half of the adjustment has been made and the bubble moves, it shows that the axis of the wyes and the axis of the level-tube are not in the same vertical plane although both have been made horizontal. By moving one end of the level-tube *sidewise* by means of the horizontal screws at one end of the tube, the two axes may be brought into the same plane. As this adjustment is liable to disturb the other, both should be alternately tested until both requirements are complied with.

By these methods the axis of the bubble is made parallel to the axis of the wyes; and as this has been made parallel to the lines of collimation by means of the previous adjustment, the axis of the bubble is therefore parallel to the line of collimation.

3. *To make the line of collimation perpendicular to the vertical axis.* Level up so that the instrument is approximately level over both sets of leveling-screws. Then, after leveling carefully over one pair of screws, revolve the telescope 180° . If it is not level, adjust half of the error by means of the capstan-headed screw under one of the wyes, and the other half by the leveling-screws. Reverse again as a test.

When the first two adjustments have been accurately made, good leveling may always be done by bringing the bubble to the center by means of the leveling-screws, at every sight if necessary, even if the third adjustment is not made. Of course this third adjustment should be made as a matter of convenience, so that the line of collimation may be always level no matter in what direction it may be pointed, but it is not *necessary* to stop work to make this adjustment every time it is found to be defective.

ADJUSTMENTS OF THE DUMPY LEVEL.

1. *To make the axis of the level-tube perpendicular to the vertical axis.* Level up so that the instrument is approximately level over both sets of leveling-screws. Then, after leveling carefully over one pair of screws, revolve the telescope 180° . If

it is not level, adjust *one-half* of the error by means of the adjusting-screws at one end of the bubble, and the other half by means of the leveling-screws. Reverse again as a test.

2. *To make the line of collimation perpendicular to the vertical axis.* The method of adjustment is identical with that for the transit (No. 4, p. 308) except that the cross-wire must be adjusted to agree with the level-bubble rather than *vice versa*, as is the case with the corresponding adjustment of the transit; i.e., with the level-bubble in the center, raise or lower the horizontal cross-wire until it points at the mark known to be on a level with the center of the instrument.

If the instrument has been well made and has not been distorted by rough usage, the cross-wires will intersect at the center of the field of view when adjusted as described. If they do not, it indicates an error which ordinarily can only be corrected by an instrument-maker. The error may be due to any one of several causes, which are

- (a) faulty centering of object-slide;
- (b) faulty centering of eyepiece;
- (c) distortion of instrument so that the geometric axis of the telescope is not perpendicular to the vertical axis. If the error is only just perceptible, it will not probably cause any error in the work.

EXPLANATORY NOTE ON THE USE OF THE TABLES.

The logarithms here given are “five-place,” but the last figure sometimes has a special mark over it (e.g., $\hat{6}$) which indicates that one-half a unit in the last place should be *added*. For example :

the value	includes all values between
.69586	.6958575000 + and .6958624999 . . .
.6958 $\hat{6}$	.6958625000 + and .6958674999 . . .

The maximum error in any one value therefore does not exceed one-quarter of a fifth-place unit.

When adding or subtracting such logarithms allow a half-unit for such a sign. For example :

.69586	.69586	.6958 $\hat{6}$
.10841	.1084 $\hat{1}$	.1084 $\hat{1}$
.1294 $\hat{7}$	.1294 $\hat{7}$	.1294 $\hat{7}$
<hr/>	<hr/>	<hr/>
.9337 $\hat{4}$	.93375	.9337 $\hat{5}$

All other logarithmic operations are performed as usual and are supposed to be understood by the student.

TABLE I.—RADII OF CURVES.

Deg.	0°		1°		2°		3°		Deg.
Min.	Radius.	Log R	Radius.	Log R	Radius.	Log R	Radius.	Log R	Min.
0	∞	∞	5729.6	3.75813	2864.9	3.45711	1910.1	3.28105	0
1	343775	5.53627	5635.7	.75095	2841.3	.45351	1899.5	.27864	1
2	171887	5.23524	5544.8	.74389	2818.0	.44993	1889.1	.27623	2
3	114592	5.05915	5456.8	.73694	2795.1	.44639	1878.8	.27387	3
4	85944	4.93421	5371.6	.73010	2772.5	.44287	1868.6	.27151	4
5	68755	4.83730	5288.9	.72336	2750.4	.43939	1858.5	.26915	5
6	57296	4.75812	5208.8	3.71673	2728.5	3.43593	1848.5	3.26681	6
7	49111	.69117	5131.0	.71020	2707.0	.43249	1838.6	.26448	7
8	42972	.63318	5055.6	.70377	2685.9	.42909	1828.8	.26217	8
9	38197	.58203	4982.3	.69743	2665.1	.42571	1819.1	.25986	9
10	34377	.53627	4911.2	.69118	2644.6	.42235	1809.6	.25757	10
11	31252	4.49488	4842.0	3.68502	2624.4	3.41903	1800.1	3.25529	11
12	28648	.45709	4774.7	.67895	2604.5	.41572	1790.7	.25303	12
13	26444	.42233	4709.3	.67296	2584.9	.41245	1781.5	.25077	13
14	24555	.39014	4645.7	.66705	2565.6	.40919	1772.3	.24853	14
15	22918	.36018	4583.8	.66122	2546.6	.40597	1763.2	.24629	15
16	21486	4.33215	4523.4	3.65547	2527.9	3.40276	1754.2	3.24407	16
17	20222	.30582	4464.7	.64979	2509.5	.39958	1745.3	.24186	17
18	19099	.28100	4407.5	.64419	2491.3	.39642	1736.5	.23967	18
19	18093	.25752	4351.7	.63865	2473.4	.39329	1727.8	.23748	19
20	17189	.23524	4297.3	.63319	2455.7	.39017	1719.1	.23530	20
21	16370	4.21405	4244.2	3.62780	2438.3	3.38708	1710.6	3.23314	21
22	15626	.19385	4192.5	.62247	2421.1	.38401	1702.1	.23098	22
23	14947	.17454	4142.0	.61720	2404.2	.38097	1693.7	.22884	23
24	14324	.15606	4092.7	.61200	2387.5	.37794	1685.4	.22670	24
25	13751	.13833	4044.5	.60686	2371.0	.37494	1677.2	.22458	25
26	13222	4.12130	3997.5	3.60178	2354.8	3.37195	1669.1	3.22247	26
27	12732	.10491	3951.5	.59676	2338.8	.36899	1661.0	.22037	27
28	12278	.08917	3906.6	.59180	2323.0	.36604	1653.0	.21827	28
29	11854	.07387	3862.7	.58689	2307.4	.36312	1645.1	.21619	29
30	11459	.05915	3819.8	.58204	2292.0	.36021	1637.3	.21412	30
31	11090	4.04491	3777.9	3.57724	2276.8	3.35733	1629.5	3.21206	31
32	10743	.03112	3736.8	.57250	2261.9	.35446	1621.8	.21000	32
33	10417	.01776	3696.6	.56780	2247.1	.35162	1614.2	.20796	33
34	10111	4.00479	3657.3	.56316	2232.5	.34879	1606.7	.20593	34
35	9822.2	3.99221	3618.8	.55856	2218.1	.34598	1599.2	.20390	35
36	9549.3	3.97997	3581.1	3.55401	2203.9	3.34318	1591.8	3.20189	36
37	9291.3	.96807	3544.2	.54951	2189.8	.34041	1584.5	.19988	37
38	9046.7	.95649	3508.0	.54506	2176.0	.33765	1577.2	.19789	38
39	8814.8	.94521	3472.6	.54065	2162.3	.33491	1570.0	.19590	39
40	8594.4	.93421	3437.9	.53629	2148.8	.33219	1562.9	.19392	40
41	8384.8	3.92349	3403.8	3.53197	2135.4	3.32949	1555.8	3.19195	41
42	8185.2	.91302	3370.5	.52769	2122.3	.32680	1548.8	.18999	42
43	7994.8	.90281	3337.7	.52345	2109.2	.32412	1541.9	.18804	43
44	7813.1	.89282	3305.7	.51925	2096.4	.32147	1535.0	.18610	44
45	7639.5	.88306	3274.2	.51510	2083.7	.31883	1528.2	.18417	45
46	7473.4	3.87352	3243.3	3.51098	2071.1	3.31621	1521.4	3.18224	46
47	7314.4	.86418	3213.0	.50691	2058.7	.31360	1514.7	.18032	47
48	7162.0	.85503	3183.2	.50287	2046.5	.31101	1508.1	.17842	48
49	7015.9	.84608	3154.0	.49886	2034.4	.30843	1501.5	.17652	49
50	6875.6	.83731	3125.4	.49490	2022.4	.30587	1495.0	.17462	50
51	6740.7	3.82871	3097.2	3.49097	2010.6	3.30332	1488.5	3.17274	51
52	6611.1	.82027	3069.6	.48707	1998.9	.30079	1482.1	.17087	52
53	6486.4	.81200	3042.4	.48321	1987.3	.29827	1475.7	.16900	53
54	6366.3	.80388	3015.7	.47939	1975.9	.29577	1469.4	.16714	54
55	6250.5	.79591	2989.5	.47559	1964.6	.29328	1463.2	.16529	55
56	6138.9	3.78809	2963.7	3.47183	1953.5	3.29081	1457.0	3.16341	56
57	6031.2	.78040	2938.4	.46811	1942.4	.28835	1450.8	.16161	57
58	5927.2	.77285	2913.5	.46441	1931.5	.28590	1444.7	.15978	58
59	5826.8	.76542	2889.0	.46075	1920.7	.28347	1438.7	.15796	59
60	5729.6	.75813	2864.9	.45711	1910.1	.28105	1432.7	.15615	60

TABLE I.—RADII OF CURVES.

Deg.	4°		5°		6°		7°		Deg.
Min.	Radius.	Log R	Radius.	Log R	Radius.	Log R	Radius.	Log R	Min.
0	1432.7	3.15615	1146.3	3.05929	955.37	2.98017	819.02	2.91329	0
1	1426.7	.15434	1142.5	.05784	952.72	.97896	817.08	.91226	1
2	1420.8	.15255	1138.7	.05640	950.09	.97776	815.14	.91123	2
3	1415.0	.15076	1134.9	.05497	947.48	.97657	813.22	.91021	3
4	1409.2	.14897	1131.2	.05354	944.88	.97537	811.30	.90918	4
5	1403.5	.14720	1127.5	.05211	942.29	.97418	809.40	.90816	5
6	1397.8	3.14543	1123.8	3.05069	939.72	2.97300	807.50	2.90714	6
7	1392.1	.14367	1120.2	.04928	937.16	.97181	805.61	.90612	7
8	1386.5	.14191	1116.5	.04787	934.62	.97063	803.73	.90511	8
9	1380.9	.14017	1112.9	.04646	932.09	.96945	801.86	.90410	9
10	1375.4	.13843	1109.3	.04506	929.57	.96828	800.00	.90309	10
11	1369.9	3.13669	1105.8	3.04366	927.07	2.96711	798.14	2.90208	11
12	1364.5	.13497	1102.2	.04227	924.58	.96594	796.30	.90107	12
13	1359.1	.13325	1098.7	.04088	922.10	.96478	794.46	.90007	13
14	1353.8	.13154	1095.2	.03949	919.64	.96361	792.63	.89907	14
15	1348.4	.12983	1091.7	.03811	917.19	.96246	790.81	.89807	15
16	1343.2	3.12813	1088.3	3.03674	914.75	2.96130	789.00	2.89708	16
17	1338.0	.12644	1084.8	.03537	912.33	.96015	787.20	.89608	17
18	1332.8	.12473	1081.4	.03400	909.92	.95900	785.41	.89509	18
19	1327.6	.12307	1078.1	.03264	907.52	.95783	783.62	.89410	19
20	1322.5	.12140	1074.7	.03128	905.13	.95671	781.84	.89312	20
21	1317.5	3.11974	1071.3	3.02992	902.76	2.95557	780.07	2.89213	21
22	1312.4	.11808	1068.0	.02857	900.40	.95443	778.31	.89115	22
23	1307.4	.11642	1064.7	.02723	898.05	.95330	776.55	.89017	23
24	1302.5	.11477	1061.4	.02589	895.71	.95217	774.81	.88919	24
25	1297.6	.11313	1058.2	.02455	893.39	.95104	773.07	.88821	25
26	1292.7	3.11150	1054.9	3.02322	891.08	2.94991	771.34	2.88724	26
27	1287.9	.10987	1051.7	.02189	888.78	.94879	769.61	.88627	27
28	1283.1	.10825	1048.5	.02056	886.49	.94767	767.90	.88530	28
29	1278.3	.10663	1045.3	.01924	884.21	.94653	766.19	.88433	29
30	1273.6	.10502	1042.1	.01792	881.95	.94544	764.49	.88337	30
31	1268.9	3.10341	1039.0	3.01661	879.69	2.94433	762.80	2.88241	31
32	1264.2	.10182	1035.9	.01530	877.45	.94322	761.11	.88145	32
33	1259.6	.10022	1032.8	.01400	875.22	.94212	759.43	.88049	33
34	1255.0	.09864	1029.7	.01270	873.00	.94101	757.76	.87953	34
35	1250.4	.09703	1026.6	.01140	870.80	.93991	756.10	.87858	35
36	1245.9	3.09548	1023.5	3.01010	868.60	2.93882	754.44	2.87762	36
37	1241.4	.09391	1020.5	.00882	866.41	.93772	752.80	.87668	37
38	1236.9	.09234	1017.5	.00753	864.24	.93663	751.16	.87573	38
39	1232.5	.09079	1014.5	.00625	862.07	.93554	749.52	.87478	39
40	1228.1	.08923	1011.5	.00497	859.92	.93446	747.89	.87384	40
41	1223.7	3.08769	1008.6	3.00370	857.78	2.93337	746.27	2.87290	41
42	1219.4	.08614	1005.6	.00242	855.65	.93229	744.66	.87196	42
43	1215.1	.08461	1002.7	3.00116	853.53	.93122	743.06	.87102	43
44	1210.8	.08308	999.76	2.99989	851.42	.93014	741.46	.87008	44
45	1206.6	.08153	996.87	.99863	849.32	.92907	739.86	.86915	45
46	1202.4	3.08003	993.99	2.99738	847.23	2.92800	738.28	2.86822	46
47	1198.2	.07852	991.13	.99613	845.15	.92693	736.70	.86729	47
48	1194.0	.07701	988.28	.99488	843.08	.92587	735.13	.86636	48
49	1189.9	.07550	985.45	.99363	841.02	.92480	733.56	.86544	49
50	1185.8	.07400	982.64	.99239	838.97	.92374	732.01	.86451	50
51	1181.7	3.07251	979.84	2.99113	836.93	2.92269	730.45	2.86359	51
52	1177.7	.07102	977.06	.98992	834.90	.92163	728.91	.86267	52
53	1173.6	.06954	974.29	.98869	832.89	.92058	727.37	.86173	53
54	1169.7	.06806	971.54	.98746	830.88	.91953	725.84	.86084	54
55	1165.7	.06658	968.81	.98624	828.88	.91849	724.31	.85992	55
56	1161.8	3.06511	966.09	2.98501	826.89	2.91744	722.79	2.85901	56
57	1157.9	.06363	963.39	.98380	824.91	.91640	721.28	.85810	57
58	1154.0	.06219	960.70	.98258	822.93	.91536	719.77	.85719	58
59	1150.1	.06074	958.03	.98137	820.97	.91433	718.27	.85629	59
60	1146.3	.05929	955.37	.98017	819.02	.91329	716.78	.85538	60

TABLE I.—RADII OF CURVES.

Deg.	8°		9°		10°		11°		Deg.
Min.	Radius.	Log R	Radius.	Log R	Radius.	Log R	Radius.	Log R	Min.
0	716.78	2.85538	637.27	2.80432	573.69	2.75867	521.67	2.71739	0
1	715.29	.85448	636.10	.80352	572.73	.75795	520.88	.71674	1
2	713.81	.85358	634.93	.80272	571.78	.75723	520.10	.71608	2
3	712.34	.85268	633.76	.80192	570.84	.75651	519.32	.71543	3
4	710.87	.85178	632.60	.80113	569.90	.75579	518.54	.71478	4
5	709.40	.85089	631.44	.80033	568.96	.75508	517.76	.71413	5
6	707.95	2.85000	630.29	2.79954	568.02	2.75436	516.99	2.71348	6
7	706.49	.84911	629.14	.79874	567.09	.75365	516.21	.71283	7
8	705.05	.84822	627.99	.79795	566.16	.75293	515.44	.71218	8
9	703.61	.84733	626.85	.79716	565.23	.75222	514.68	.71153	9
10	702.17	.84644	625.71	.79637	564.31	.75151	513.91	.71088	10
11	700.75	2.84556	624.58	2.79558	563.38	2.75080	513.15	2.71024	11
12	699.33	.84468	623.45	.79480	562.47	.75009	512.38	.70959	12
13	697.91	.84380	622.32	.79401	561.55	.74939	511.63	.70895	13
14	696.50	.84292	621.20	.79323	560.64	.74868	510.87	.70831	14
15	695.09	.84204	620.09	.79245	559.73	.74798	510.11	.70767	15
16	693.70	2.84117	618.97	2.79167	558.82	2.74727	509.36	2.70702	16
17	692.30	.84029	617.87	.79089	557.92	.74657	508.61	.70638	17
18	690.91	.83942	616.76	.79011	557.02	.74587	507.86	.70575	18
19	689.53	.83855	615.66	.78934	556.12	.74517	507.12	.70511	19
20	688.16	.83768	614.56	.78856	555.23	.74447	506.38	.70447	20
21	686.78	2.83682	613.47	2.78779	554.34	2.74377	505.64	2.70383	21
22	685.42	.83595	612.38	.78702	553.45	.74307	504.90	.70320	22
23	684.06	.83509	611.30	.78625	552.56	.74238	504.16	.70257	23
24	682.70	.83423	610.21	.78548	551.68	.74168	503.42	.70193	24
25	681.35	.83337	609.14	.78471	550.80	.74099	502.69	.70130	25
26	680.01	2.83251	608.06	2.78395	549.92	2.74030	501.96	2.70067	26
27	678.67	.83166	606.99	.78318	549.05	.73961	501.23	.70004	27
28	677.34	.83080	605.93	.78242	548.17	.73892	500.51	.69941	28
29	676.01	.82995	604.86	.78165	547.30	.73823	499.78	.69878	29
30	674.69	.82910	603.80	.78089	546.44	.73754	499.06	.69815	30
31	673.37	2.82825	602.75	2.78013	545.57	2.73685	498.34	2.69752	31
32	672.06	.82740	601.70	.77938	544.71	.73617	497.62	.69690	32
33	670.75	.82656	600.65	.77862	543.86	.73548	496.91	.69627	33
34	669.45	.82571	599.61	.77786	543.00	.73480	496.19	.69565	34
35	668.15	.82487	598.57	.77711	542.15	.73412	495.48	.69503	35
36	666.86	2.82403	597.53	2.77636	541.30	2.73343	494.77	2.69440	36
37	665.57	.82319	596.50	.77561	540.45	.73275	494.07	.69378	37
38	664.29	.82235	595.47	.77486	539.61	.73207	493.36	.69316	38
39	663.01	.82152	594.44	.77411	538.76	.73140	492.66	.69254	39
40	661.74	.82068	593.42	.77336	537.92	.73072	491.96	.69192	40
41	660.47	2.81985	592.40	2.77261	537.09	2.73004	491.26	2.69131	41
42	659.21	.81902	591.38	.77187	536.25	.72937	490.56	.69069	42
43	657.95	.81819	590.37	.77112	535.42	.72869	489.86	.69007	43
44	656.69	.81736	589.36	.77038	534.59	.72802	489.17	.68946	44
45	655.45	.81653	588.36	.76964	533.77	.72735	488.48	.68884	45
46	654.20	2.81571	587.36	2.76890	532.94	2.72668	487.79	2.68823	46
47	652.96	.81489	586.36	.76816	532.12	.72601	487.10	.68762	47
48	651.73	.81406	585.36	.76742	531.30	.72534	486.42	.68701	48
49	650.50	.81324	584.37	.76669	530.49	.72467	485.73	.68640	49
50	649.27	.81243	583.38	.76595	529.67	.72401	485.05	.68579	50
51	648.05	2.81161	582.40	2.76522	528.86	2.72334	484.37	2.68518	51
52	646.84	.81079	581.42	.76449	528.05	.72267	483.69	.68457	52
53	645.63	.80998	580.44	.76376	527.25	.72201	483.02	.68396	53
54	644.42	.80917	579.47	.76303	526.44	.72135	482.34	.68335	54
55	643.22	.80836	578.49	.76230	525.64	.72069	481.67	.68275	55
56	642.02	2.80755	577.53	2.76157	524.84	2.72003	481.00	2.68214	56
57	640.83	.80674	576.56	.76084	524.05	.71937	480.33	.68154	57
58	639.64	.80593	575.60	.76012	523.25	.71871	479.67	.68094	58
59	638.45	.80513	574.64	.75939	522.46	.71805	479.00	.68033	59
60	637.27	.80432	573.69	.75867	521.67	.71739	478.34	.67973	60

TABLE I.—RADII OF CURVES.

Deg.	Radius.	Log R	Deg.	Radius.	Log R	Deg.	Radius.	Log R	Deg.	Radius.	Log R
12°	478.34	2.67973	14°	410.28	2.61307	16°	359.26	2.55541	21°	274.37	2.43833
2	477.02	.67853	2	409.31	.61205	5	357.42	.55317	10	272.23	.43494
4	475.71	.67734	4	408.34	.61102	10	355.59	.55094	20	270.13	.43157
6	474.40	.67614	6	407.38	.61000	15	353.77	.54872	30	268.06	.42823
8	473.10	.67493	8	406.42	.60898	20	351.98	.54652	40	266.02	.42492
10	471.81	2.67376	10	405.47	2.60796	25	350.21	.54432	50	264.02	.42163
12	470.53	.67258	12	404.53	.60694	30	348.45	2.54214	22°	262.04	2.41837
14	469.25	.67140	14	403.58	.60593	35	346.71	.53997	10	260.10	.41513
16	467.98	.67022	16	402.65	.60492	40	344.99	.53786	20	258.18	.41192
18	466.72	.66905	18	401.71	.60391	45	343.29	.53563	30	256.29	.40873
20	465.46	2.66788	20	400.78	2.60291	50	341.60	.53351	40	254.43	.40557
22	464.21	.66671	22	399.86	.60190	55	339.93	.53138	50	252.60	.40243
24	462.97	.66555	24	398.94	.60090	17°	338.27	2.52927	28°	250.79	2.39931
26	461.73	.66439	26	398.02	.59990	5	336.64	.52716	10	249.01	.39622
28	460.50	.66323	28	397.11	.59891	10	335.01	.52506	20	247.26	.39315
30	459.28	2.66207	30	396.20	2.59791	15	333.41	.52297	30	245.53	.39010
32	458.06	.66092	32	395.30	.59692	20	331.82	.52090	40	243.82	.38707
34	456.85	.65977	34	394.40	.59593	25	330.24	.51883	50	242.14	.38407
36	455.65	.65863	36	393.50	.59494	30	328.68	2.51677	24°	240.49	2.38109
38	454.45	.65748	38	392.61	.59396	35	327.13	.51472	10	238.85	.37813
40	453.26	2.65634	40	391.72	2.59298	40	325.60	.51269	20	237.24	.37519
42	452.07	.65521	42	390.84	.59199	45	324.09	.51066	30	235.65	.37227
44	450.89	.65407	44	389.96	.59102	50	322.59	.50864	40	234.08	.36937
46	449.72	.65294	46	389.08	.59004	55	321.10	.50663	50	232.54	.36649
48	448.56	.65181	48	388.21	.58907	18°	319.62	2.50464	25°	231.01	2.36363
50	447.40	2.65069	50	387.34	2.58809	5	318.16	.50265	30	226.55	.35517
52	446.24	.64957	52	386.48	.58713	10	316.71	.50067	26°	222.27	.34688
54	445.09	.64845	54	385.62	.58616	15	315.28	.49869	30	218.15	.33873
56	443.95	.64733	56	384.77	.58519	20	313.86	.49673	27°	214.18	2.33078
58	442.81	.64622	58	383.91	.58423	25	312.45	.49478	30	210.36	.32296
13°	441.68	2.64511	15°	383.06	2.58327	30	311.06	2.49284	28°	206.68	.31529
2	440.56	.64400	2	382.22	.58231	35	309.67	.49090	30	203.13	.30776
4	439.44	.64290	4	381.38	.58135	40	308.30	.48898	29°	199.70	2.30037
6	438.33	.64180	6	380.54	.58040	45	306.95	.48706	30	196.38	.29310
8	437.22	.64070	8	379.71	.57945	50	305.60	.48515	30°	193.19	.28597
10	436.12	2.63960	10	378.88	2.57850	55	304.27	.48325	30	190.09	.27896
12	435.02	.63851	12	378.05	.57753	19°	302.94	2.48136	31°	187.10	2.27207
14	433.93	.63742	14	377.23	.57661	5	301.63	.47948	32°	181.40	.25863
16	432.84	.63633	16	376.41	.57566	10	300.33	.47760	33°	176.05	.24563
18	431.76	.63524	18	375.60	.57472	15	299.04	.47573	34°	171.02	.23303
20	430.69	2.63416	20	374.79	2.57378	20	297.77	.47388	35°	166.28	.22083
22	429.62	.63308	22	373.98	.57284	25	296.50	.47203	36°	161.80	2.20899
24	428.56	.63201	24	373.17	.57191	30	295.25	2.47018	37°	157.58	.19749
26	427.50	.63093	26	372.37	.57097	35	294.00	.46835	38°	153.58	.18633
28	426.44	.62986	28	371.57	.57004	40	292.77	.46652	39°	149.79	.17547
30	425.40	2.62879	30	370.78	2.56911	45	291.55	.46471	40	146.19	.16492
32	424.35	.62773	32	369.99	.56819	50	290.33	.46289	41°	142.77	2.15464
34	423.32	.62666	34	369.20	.56726	55	289.13	.46109	42°	139.52	.14464
36	422.28	.62560	36	368.42	.56634	20	287.94	2.45930	43°	136.43	.13489
38	421.26	.62454	38	367.64	.56542	5	286.76	.45751	44°	133.47	.12539
40	420.23	2.62349	40	366.86	2.56450	10	285.58	.45573	45°	130.66	.11613
42	419.22	.62243	42	366.09	.56358	15	284.42	.45396	46°	127.97	2.10709
44	418.20	.62138	44	365.31	.56266	20	283.27	.45219	47°	125.39	.09827
46	417.19	.62034	46	364.55	.56175	25	282.12	.45044	48°	122.93	.08963
48	416.19	.61929	48	363.78	.56084	30	280.99	2.44869	49°	120.57	.08124
50	415.19	2.61825	50	363.02	2.55993	35	279.86	.44694	50	118.31	.07302
52	414.20	.61721	52	362.26	.55902	40	278.75	.44521	52°	114.06	2.05713
54	413.21	.61617	54	361.51	.55812	45	277.64	.44348	54°	110.13	.04192
56	412.23	.61514	56	360.76	.55721	50	276.54	.44176	56°	106.50	.02736
58	411.25	.61410	58	360.01	.55631	55	275.45	.44004	58°	103.13	.01340
14°	410.28	2.61307	16°	359.26	2.55541	21°	274.37	2.43833	60	100.00	2.00000

'ABLE II.—TANGENTS, EXTERNAL DISTANCES, AND LONG CHORDS FOR A
1° CURVE.

Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.
1°	50.00	0.218	100.00	11°	551.70	26.500	1098.3	21°	1061.9	97.58	2088.3
10'	58.34	0.297	116.67	10	560.11	27.313	1114.9	10	1070.6	99.15	2104.7
20	66.67	0.388	133.33	20	568.53	28.137	1131.5	20	1079.2	100.75	2121.1
30	75.01	0.491	150.00	30	576.95	28.974	1148.1	30	1087.8	102.35	2137.5
40	83.34	0.606	166.66	40	585.36	29.824	1164.7	40	1096.4	103.97	2153.9
50	91.68	0.733	183.33	50	593.79	30.686	1181.2	50	1105.1	105.60	2170.2
2°	100.01	0.873	199.99	12°	602.21	31.561	1197.8	22°	1113.7	107.24	2186.5
10	108.35	1.024	216.66	10	610.64	32.447	1214.4	10	1122.4	108.90	2202.9
20	116.68	1.188	233.32	20	619.07	33.347	1231.0	20	1131.0	110.57	2219.2
30	125.02	1.364	249.98	30	627.50	34.259	1247.5	30	1139.7	112.25	2235.5
40	133.36	1.552	266.65	40	635.93	35.183	1264.1	40	1148.4	113.95	2251.9
50	141.70	1.752	283.31	50	644.37	36.120	1280.7	50	1157.0	115.66	2268.2
3°	150.04	1.964	299.97	18°	652.81	37.069	1297.2	28°	1165.7	117.38	2284.5
10	158.38	2.188	316.63	10	661.25	38.031	1313.8	10	1174.4	119.12	2300.9
20	166.72	2.425	333.29	20	669.70	39.006	1330.3	20	1183.1	120.87	2317.2
30	175.06	2.674	349.95	30	678.15	39.993	1346.9	30	1191.8	122.63	2333.5
40	183.40	2.934	366.61	40	686.60	40.992	1363.4	40	1200.5	124.41	2349.9
50	191.74	3.207	383.27	50	695.06	42.004	1380.0	50	1209.2	126.20	2366.2
4°	200.08	3.492	399.92	14°	703.51	43.029	1396.5	24°	1217.9	128.00	2382.5
10	208.43	3.790	416.58	10	711.97	44.066	1413.1	10	1226.6	129.82	2398.9
20	216.77	4.099	433.24	20	720.44	45.116	1429.6	20	1235.3	131.65	2415.2
30	225.12	4.421	449.89	30	728.90	46.178	1446.2	30	1244.0	133.50	2431.5
40	233.47	4.755	466.54	40	737.37	47.253	1462.7	40	1252.8	135.36	2447.9
50	241.81	5.100	483.20	50	745.85	48.341	1479.2	50	1261.5	137.23	2464.2
5°	250.16	5.459	499.85	15°	754.32	49.441	1495.7	25°	1270.2	139.11	2480.5
10	258.51	5.829	516.50	10	762.80	50.554	1512.3	10	1279.0	141.01	2496.9
20	266.86	6.211	533.15	20	771.29	51.679	1528.8	20	1287.7	142.93	2513.2
30	275.21	6.606	549.80	30	779.77	52.818	1545.3	30	1296.5	144.85	2529.5
40	283.57	7.013	566.44	40	788.26	53.969	1561.8	40	1305.3	146.79	2545.9
50	291.92	7.432	583.09	50	796.75	55.132	1578.3	50	1314.0	148.75	2562.2
6°	300.28	7.863	599.73	16°	805.25	56.309	1594.8	26°	1322.8	150.71	2578.5
10	308.64	8.307	616.38	10	813.75	57.498	1611.3	10	1331.6	152.69	2594.9
20	316.99	8.762	633.02	20	822.25	58.699	1627.8	20	1340.4	154.69	2611.2
30	325.35	9.230	649.66	30	830.76	59.914	1644.3	30	1349.2	156.70	2627.5
40	333.71	9.710	666.30	40	839.27	61.141	1660.8	40	1358.0	158.72	2643.9
50	342.08	10.202	682.94	50	847.78	62.381	1677.3	50	1366.8	160.76	2660.2
7°	350.44	10.707	699.57	17°	856.30	63.634	1693.8	27°	1375.6	162.81	2676.5
10	358.81	11.224	716.21	10	864.82	64.900	1710.3	10	1384.4	164.87	2692.9
20	367.17	11.753	732.84	20	873.35	66.178	1726.8	20	1393.2	166.95	2709.2
30	375.54	12.294	749.47	30	881.88	67.470	1743.2	30	1402.0	169.04	2725.5
40	383.91	12.847	766.10	40	890.41	68.774	1759.7	40	1410.9	171.15	2741.9
50	392.28	13.413	782.73	50	898.95	70.091	1776.2	50	1419.7	173.27	2758.2
8°	400.66	13.991	799.36	18°	907.49	71.421	1792.6	28°	1428.6	175.41	2774.5
10	409.03	14.582	815.99	10	916.03	72.764	1809.1	10	1437.4	177.55	2790.9
20	417.41	15.184	832.61	20	924.58	74.119	1825.5	20	1446.3	179.72	2807.2
30	425.79	15.799	849.23	30	933.13	75.488	1842.0	30	1455.1	181.89	2823.5
40	434.17	16.426	865.85	40	941.69	76.869	1858.4	40	1464.0	184.08	2839.9
50	442.55	17.066	882.47	50	950.25	78.264	1874.9	50	1472.9	186.29	2856.2
9°	450.93	17.717	899.09	19°	958.81	79.671	1891.3	29°	1481.8	188.51	2872.5
10	459.32	18.381	915.70	10	967.38	81.092	1907.8	10	1490.7	190.74	2888.9
20	467.71	19.058	932.31	20	975.96	82.525	1924.2	20	1499.6	192.99	2905.2
30	476.10	19.746	948.92	30	984.53	83.972	1940.6	30	1508.5	195.25	2921.5
40	484.49	20.447	965.53	40	993.12	85.431	1957.1	40	1517.4	197.53	2937.9
50	492.88	21.161	982.14	50	1001.70	86.904	1973.5	50	1526.3	199.82	2954.2
10°	501.28	21.886	998.74	20°	1010.29	88.389	1989.9	30°	1535.3	202.12	2970.5
10	509.68	22.624	1015.35	10	1018.89	89.888	2006.3	10	1544.2	204.44	2986.9
20	518.08	23.375	1031.95	20	1027.49	91.399	2022.7	20	1553.1	206.77	3003.2
30	526.48	24.138	1048.54	30	1036.09	92.924	2039.1	30	1562.1	209.12	3019.5
40	534.89	24.913	1065.14	40	1044.70	94.462	2055.5	40	1571.0	211.48	3035.9
50	543.29	25.700	1081.73	50	1053.31	96.013	2071.9	50	1580.0	213.86	3052.2
11°	551.70	26.500	1098.33	21°	1061.93	97.577	2088.3	31°	1589.0	216.25	3068.5

TABLE II.—TANGENTS, EXTERNAL DISTANCES, AND LONG CHORDS FOR A
1° CURVE.

Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.
31°	1589.0	216.25	3062.4	41°	2142.2	387.38	4013.1	51°	2732.9	618.39	4933.4
10'	1598.0	218.66	3078.4	10	2151.7	390.71	4028.7	10	2743.1	622.81	4948.4
20	1606.9	221.08	3094.5	20	2161.2	394.06	4044.3	20	2753.4	627.24	4963.4
30	1615.9	223.51	3110.5	30	2170.8	397.43	4059.9	30	2763.7	631.69	4978.4
40	1624.9	225.96	3126.6	40	2180.3	400.82	4075.5	40	2773.9	636.16	4993.4
50	1633.9	228.42	3142.6	50	2189.9	404.22	4091.1	50	2784.2	640.66	5008.4
32°	1643.0	230.90	3158.6	42°	2199.4	407.64	4106.6	52°	2794.5	645.17	5023.4
10	1652.0	233.39	3174.6	10	2209.0	411.07	4122.2	10	2804.9	649.70	5038.4
20	1661.0	235.90	3190.6	20	2218.6	414.52	4137.7	20	2815.2	654.25	5053.4
30	1670.0	238.43	3206.6	30	2228.1	417.99	4153.3	30	2825.6	658.83	5068.3
40	1679.1	240.96	3222.6	40	2237.7	421.48	4168.8	40	2835.9	663.42	5083.3
50	1688.1	243.52	3238.6	50	2247.3	424.98	4184.3	50	2846.3	668.03	5098.2
33°	1697.2	246.08	3254.6	43°	2257.0	428.50	4199.8	53°	2856.7	672.66	5113.1
10	1706.3	248.66	3270.6	10	2266.6	432.04	4215.3	10	2867.1	677.32	5128.0
20	1715.3	251.26	3286.6	20	2276.2	435.59	4230.8	20	2877.5	681.99	5142.9
30	1724.4	253.87	3302.5	30	2285.9	439.16	4246.3	30	2888.0	686.68	5157.8
40	1733.5	256.50	3318.5	40	2295.6	442.75	4261.8	40	2898.4	691.40	5172.7
50	1742.6	259.14	3334.4	50	2305.2	446.35	4277.3	50	2908.9	696.13	5187.6
34°	1751.7	261.80	3350.4	44°	2314.9	449.98	4292.7	54°	2919.4	700.89	5202.4
10	1760.8	264.47	3366.3	10	2324.6	453.62	4308.2	10	2929.9	705.66	5217.3
20	1770.0	267.16	3382.2	20	2334.3	457.27	4323.6	20	2940.4	710.46	5232.1
30	1779.1	269.86	3398.2	30	2344.1	460.95	4339.0	30	2951.0	715.28	5246.9
40	1788.2	272.58	3414.1	40	2353.8	464.64	4354.5	40	2961.5	720.11	5261.7
50	1797.4	275.31	3430.0	50	2363.5	468.35	4369.9	50	2972.1	724.97	5276.5
35°	1806.6	278.05	3445.9	45°	2373.3	472.08	4385.3	55°	2982.7	729.85	5291.3
10	1815.7	280.82	3461.8	10	2383.1	475.82	4400.7	10	2993.3	734.76	5306.1
20	1824.9	283.60	3477.7	20	2392.8	479.59	4416.1	20	3003.9	739.68	5320.9
30	1834.1	286.39	3493.5	30	2402.6	483.37	4431.4	30	3014.5	744.62	5335.6
40	1843.3	289.20	3509.4	40	2412.4	487.16	4446.8	40	3025.2	749.59	5350.4
50	1852.5	292.02	3525.3	50	2422.3	490.98	4462.2	50	3035.8	754.57	5365.1
36°	1861.7	294.86	3541.1	46°	2432.1	494.82	4477.5	56°	3046.5	759.58	5379.8
10	1870.9	297.72	3557.0	10	2441.9	498.67	4492.8	10	3057.2	764.61	5394.5
20	1880.1	300.59	3572.8	20	2451.8	502.54	4508.2	20	3067.9	769.66	5409.2
30	1889.4	303.47	3588.6	30	2461.7	506.42	4523.5	30	3078.7	774.73	5423.9
40	1898.6	306.37	3604.5	40	2471.5	510.33	4538.8	40	3089.4	779.83	5438.6
50	1907.9	309.29	3620.3	50	2481.4	514.25	4554.1	50	3100.2	784.94	5453.3
37°	1917.1	312.22	3636.1	47°	2491.3	518.20	4569.4	57°	3110.9	790.08	5467.9
10	1926.4	315.17	3651.9	10	2501.2	522.16	4584.7	10	3121.7	795.24	5482.5
20	1935.7	318.13	3667.7	20	2511.2	526.13	4599.9	20	3132.6	800.42	5497.2
30	1945.0	321.11	3683.5	30	2521.1	530.13	4615.2	30	3143.4	805.62	5511.8
40	1954.3	324.11	3699.3	40	2531.1	534.15	4630.4	40	3154.2	810.85	5526.4
50	1963.6	327.12	3715.0	50	2541.0	538.18	4645.7	50	3165.1	816.10	5541.0
38°	1972.9	330.15	3730.8	48°	2551.0	542.23	4660.9	58°	3176.0	821.37	5555.6
10	1982.2	333.19	3746.5	10	2561.0	546.30	4676.1	10	3186.9	826.66	5570.2
20	1991.5	336.25	3762.3	20	2571.0	550.39	4691.3	20	3197.8	831.98	5584.7
30	2000.9	339.32	3778.0	30	2581.0	554.50	4706.5	30	3208.8	837.31	5599.3
40	2010.2	342.41	3793.8	40	2591.1	558.63	4721.7	40	3219.7	842.67	5613.8
50	2019.6	345.52	3809.5	50	2601.1	562.77	4736.9	50	3230.7	848.06	5628.3
39°	2029.0	348.64	3825.2	49°	2611.2	566.94	4752.1	59°	3241.7	853.46	5642.8
10	2038.4	351.78	3840.9	10	2621.2	571.12	4767.3	10	3252.7	858.89	5657.3
20	2047.8	354.94	3856.6	20	2631.3	575.32	4782.4	20	3263.7	864.34	5671.8
30	2057.2	358.11	3872.3	30	2641.4	579.54	4797.5	30	3274.8	869.82	5686.3
40	2066.6	361.29	3888.0	40	2651.5	583.78	4812.7	40	3285.8	875.32	5700.8
50	2076.0	364.50	3903.6	50	2661.6	588.04	4827.8	50	3296.9	880.84	5715.2
40	2085.4	367.72	3919.3	50°	2671.8	592.32	4842.9	60°	3308.0	886.38	5729.7
10	2094.9	370.95	3935.0	10	2681.9	596.62	4858.0	10	3319.1	891.95	5744.1
20	2104.3	374.20	3950.6	20	2692.1	600.93	4873.1	20	3330.3	897.54	5758.5
30	2113.8	377.47	3966.3	30	2702.3	605.27	4888.2	30	3341.4	903.15	5772.9
40	2123.3	380.76	3981.9	40	2712.5	609.62	4903.2	40	3352.6	908.79	5787.3
50	2132.7	384.06	3997.5	50	2722.7	614.00	4918.3	50	3363.8	914.45	5801.7

TABLE II.—TANGENTS, EXTERNAL DISTANCES, AND LONG CHORDS FOR A
1° CURVE.

Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.	Δ	Tangent T.	Ext. Dist. E.	Long Ch'd LC.
61°	3375.0	920.14	5816.0	71°	4086.9	1308.2	6654.4	81°	4893.6	1805.3	7442.2
10'	3386.3	925.85	5830.4	10	4099.5	1315.5	6668.0	10	4908.0	1814.7	7454.9
20	3397.5	931.58	5844.7	20	4112.1	1322.9	6681.6	20	4922.5	1824.1	7467.5
30	3408.8	937.34	5859.1	30	4124.8	1330.3	6695.1	30	4937.0	1833.6	7480.2
40	3420.1	943.12	5873.4	40	4137.4	1337.7	6708.6	40	4951.5	1843.1	7492.8
50	3431.4	948.92	5887.7	50	4150.1	1345.1	6722.1	50	4966.1	1852.6	7505.4
62°	3442.7	954.75	5902.0	72°	4162.8	1352.6	6735.6	82°	4980.7	1862.2	7518.0
10	3454.1	960.60	5916.3	10	4175.6	1360.1	6749.1	10	4995.4	1871.8	7530.5
20	3465.4	966.48	5930.5	20	4188.4	1367.6	6762.5	20	5010.0	1881.5	7543.1
30	3476.8	972.39	5944.8	30	4201.2	1375.2	6776.0	30	5024.8	1891.2	7555.6
40	3488.2	978.31	5959.0	40	4214.0	1382.8	6789.4	40	5039.5	1900.9	7568.2
50	3499.7	984.27	5973.3	50	4226.8	1390.4	6802.8	50	5054.3	1910.7	7580.7
63°	3511.1	990.24	5987.5	73°	4239.7	1398.0	6816.3	83°	5069.2	1920.5	7593.2
10	3522.6	996.24	6001.7	10	4252.6	1405.7	6829.6	10	5084.0	1930.4	7605.6
20	3534.1	1002.3	6015.9	20	4265.6	1413.5	6843.0	20	5099.0	1940.3	7618.1
30	3545.6	1008.3	6030.0	30	4278.5	1421.2	6856.4	30	5113.9	1950.3	7630.5
40	3557.2	1014.4	6044.2	40	4291.5	1429.0	6869.7	40	5128.9	1960.2	7643.0
50	3568.7	1020.5	6058.4	50	4304.6	1436.8	6883.1	50	5143.9	1970.3	7655.4
64°	3580.3	1026.6	6072.5	74°	4317.6	1444.6	6896.4	84°	5159.0	1980.4	7667.8
10	3591.9	1032.8	6086.6	10	4330.7	1452.5	6909.7	10	5174.1	1990.5	7680.1
20	3603.5	1039.0	6100.7	20	4343.8	1460.4	6923.0	20	5189.3	2000.6	7692.5
30	3615.1	1045.2	6114.8	30	4356.9	1468.4	6936.2	30	5204.4	2010.8	7704.9
40	3626.8	1051.4	6128.9	40	4370.1	1476.4	6949.5	40	5219.7	2021.1	7717.2
50	3638.5	1057.7	6143.0	50	4383.3	1484.4	6962.8	50	5234.9	2031.4	7729.5
65°	3650.2	1063.9	6157.1	75°	4396.5	1492.4	6976.0	85°	5250.3	2041.7	7741.8
10	3661.9	1070.2	6171.1	10	4409.8	1500.5	6989.2	10	5265.6	2052.1	7754.1
20	3673.7	1076.6	6185.2	20	4423.1	1508.6	7002.4	20	5281.0	2062.5	7766.3
30	3685.4	1082.9	6199.2	30	4436.4	1516.7	7015.6	30	5296.4	2073.0	7778.6
40	3697.2	1089.3	6213.2	40	4449.7	1524.9	7028.8	40	5311.9	2083.5	7790.8
50	3709.0	1095.7	6227.2	50	4463.1	1533.1	7041.9	50	5327.4	2094.1	7803.0
66°	3720.9	1102.2	6241.2	76°	4476.5	1541.4	7055.0	86°	5343.0	2104.7	7815.2
10	3732.7	1108.6	6255.2	10	4489.9	1549.7	7068.2	10	5358.6	2115.3	7827.4
20	3744.6	1115.1	6269.1	20	4503.4	1558.0	7081.3	20	5374.2	2126.0	7839.6
30	3756.5	1121.7	6283.1	30	4516.9	1566.3	7094.4	30	5389.9	2136.7	7851.7
40	3768.5	1128.2	6297.0	40	4530.4	1574.7	7107.5	40	5405.6	2147.5	7863.8
50	3780.4	1134.8	6310.9	50	4544.0	1583.1	7120.5	50	5421.4	2158.4	7876.0
67°	3792.4	1141.4	6324.8	77°	4557.6	1591.6	7133.6	87°	5437.2	2169.2	7888.1
10	3804.4	1148.0	6338.7	10	4571.2	1600.1	7146.6	10	5453.1	2180.2	7900.1
20	3816.4	1154.7	6352.6	20	4584.8	1608.6	7159.6	20	5469.0	2191.1	7912.2
30	3828.4	1161.3	6366.4	30	4598.5	1617.1	7172.6	30	5484.9	2202.2	7924.3
40	3840.5	1168.1	6380.3	40	4612.2	1625.7	7185.6	40	5500.9	2213.2	7936.3
50	3852.6	1174.8	6394.1	50	4626.0	1634.4	7198.6	50	5517.0	2224.3	7948.3
68°	3864.7	1181.6	6408.0	78°	4639.8	1643.0	7211.6	88°	5533.1	2235.5	7960.3
10	3876.8	1188.4	6421.8	10	4653.6	1651.7	7224.5	10	5549.2	2246.7	7972.3
20	3889.0	1195.2	6435.6	20	4667.4	1660.5	7237.4	20	5565.4	2258.0	7984.2
30	3901.2	1202.0	6449.4	30	4681.3	1669.2	7250.4	30	5581.6	2269.3	7996.2
40	3913.4	1208.9	6463.1	40	4695.2	1678.1	7263.3	40	5597.8	2280.6	8008.1
50	3925.6	1215.8	6476.9	50	4709.2	1686.9	7276.1	50	5614.2	2292.0	8020.0
69°	3937.9	1222.7	6490.6	79°	4723.2	1695.8	7289.0	89°	5630.5	2303.5	8031.9
10	3950.2	1229.7	6504.4	10	4737.2	1704.7	7301.9	10	5646.9	2315.0	8043.8
20	3962.5	1236.7	6518.1	20	4751.2	1713.7	7314.7	20	5663.4	2326.6	8055.7
30	3974.8	1243.7	6531.8	30	4765.3	1722.7	7327.5	30	5679.9	2338.2	8067.5
40	3987.2	1250.8	6545.5	40	4779.4	1731.7	7340.3	40	5696.4	2349.8	8079.3
50	3999.5	1257.9	6559.1	50	4793.6	1740.8	7353.1	50	5713.0	2361.5	8091.2
70°	4011.9	1265.0	6572.8	80°	4808.7	1749.9	7365.9	90°	5729.7	2373.3	8103.0
10	4024.4	1272.1	6586.4	10	4822.0	1759.0	7378.7	10	5746.3	2385.1	8114.7
20	4036.8	1279.3	6600.1	20	4836.2	1768.2	7391.4	20	5763.1	2397.0	8126.5
30	4049.3	1286.5	6613.7	30	4850.5	1777.4	7404.1	30	5779.9	2408.9	8138.2
40	4061.8	1293.7	6627.3	40	4864.8	1786.7	7416.8	40	5796.7	2420.9	8150.0
50	4074.4	1300.9	6640.9	50	4879.2	1796.0	7429.5	50	5813.6	2432.9	8161.7
71°	4086.9	1308.2	6654.4	81°	4893.6	1805.3	7442.2	91°	5830.5	2444.9	8173.4

TABLE III.—SWITCH LEADS AND DISTANCES.

LEAD-RAILS CIRCULAR THROUGHOUT; GAUGE 4' 8½". See § 262.

Frog Number (n).	Frog Angle (F)	Lead (L) (Eq. 79).	Chord (QT) (Eq. 77).	Radius of Lead Rails (r, Eq. 78).	Log r.	Degree of Curve (d').	Frog Number (n).
4	14° 15' 00"	37.67	37.38	150.67	2.17801	38° 46'	4
4.5	12 40 59	42.37	42.12	190.69	.28032	30 24	4.5
5	11 25 16	47.08	46.85	235.42	.37183	24 32	5
5.5	10 23 20	51.79	51.58	284.85	.45462	20 13	5.5
6	9 31 38	56.50	56.30	339.00	.53020	16 58	6
6.5	8 47 51	61.21	61.03	397.85	.59972	14 26	6.5
7	8 10 16	65.92	65.75	461.42	.66409	12 26	7
7.5	7 37 41	70.62	70.47	529.69	.72402	10 50	7.5
8	7 09 10	75.33	75.19	602.67	.78007	9 31	8
8.5	6 43 59	80.04	79.90	680.36	.83273	8 26	8.5
9	6 21 35	84.75	84.62	762.75	.88238	7 31	9
9.5	6 01 32	89.46	89.33	849.85	.92934	6 45	9.5
10	5 43 29	94.17	94.05	941.67	2.97389	6 05	10
10.5	5 27 09	98.87	98.76	1038.19	3.01627	5 32	10.5
11	5 12 18	103.58	103.47	1139.42	.05668	5 02	11
11.5	4 58 45	108.29	108.19	1245.36	.09529	4 36	11.5
12	4 46 19	113.00	112.90	1356.00	3.13226	4 14	12

TURNOUTS WITH STRAIGHT POINT-RAILS AND STRAIGHT FROG-RAILS; GAUGE 4' 8½". See § 265.

Frog Number (n).	Switch Point Angle (a).	Length of Switch Point (DN).	Length of Straight Frog-rail (f).	Lead (L) (Eq. 90).	Chord (ST) (Eq. 88).	Radius of Lead-rails (r, Eq. 87).	Log r.	Degree of Curve (d').	Frog Number (n).
4	3° 40'	7.5	1.50	32.20	23.09	125.21	2.09764	47° 05'	4
4.5	3 40	7.5	1.69	34.29	25.03	159.25	.20208	36 36	4.5
5	2 45	10.0	1.87	41.85	29.88	197.65	.29589	29 22	5
5.5	2 45	10.0	2.06	44.16	32.03	240.44	.38100	24 00	5.5
6	1 50	15.0	2.25	56.00	38.66	288.09	.45953	19 59	6
6.5	1 50	15.0	2.44	58.84	41.34	340.19	.53172	16 54	6.5
7	1 50	15.0	2.62	61.65	43.98	397.65	.59950	14 27	7
7.5	1 50	15.0	2.81	64.36	46.50	460.00	.66276	12 29	7.5
8	1 50	15.0	3.00	67.04	48.99	527.91	.72256	10 52	8
8.5	1 50	15.0	3.19	69.60	51.38	600.94	.77883	9 33	8.5
9	1 50	15.0	3.37	72.20	53.80	681.16	.83325	8 25	9
9.5	1 50	15.0	3.56	74.70	56.11	767.11	.88486	7 28	9.5
10	1 50	15.0	3.75	77.04	58.28	858.14	.93356	6 41	10
10.5	1 50	15.0	3.94	79.51	60.57	959.00	2.98182	5 59	10.5
11	1 50	15.0	4.12	81.82	62.69	1065.52	3.02756	5 23	11
11.5	1 50	15.0	4.31	84.09	64.78	1180.16	3.07194	4 51	11.5
12	1 50	15.0	4.50	86.16	66.67	1299.93	3.11392	4 24	12

TRIGONOMETRICAL FUNCTIONS OF THE FROG ANGLES (F).

Frog Number (n).	Frog Angle (F).	Nat. sin F.	Nat. cos F.	Log sin F.	Log cos F.	Log cot F.	Log vers F.	Frog Number (n).
4	14° 15' 00"	.24615	.96923	9.39120	9.98642	10.59522	8.48811	4
4.5	12 40 49	.21951	.97561	.34145	.98927	.64782	.38721	4.5
5	11 25 16	.19802	.98020	.29670	.99131	.69461	.29670	5
5.5	10 23 20	.18033	.98360	.25606	.99282	.73675	.21467	5.5
6	9 31 38	.16552	.98621	.21884	.99397	.77513	.13966	6
6.5	8 47 51	.15294	.98823	.18453	.99486	.81033	.07058	6.5
7	8 10 16	.14213	.98985	.15268	.99557	.84288	8.00655	7
7.5	7 37 41	.13274	.99115	.12301	.99614	.87313	7.94691	7.5
8	7 09 10	.12452	.99222	.09522	.99660	.90138	.89110	8
8.5	6 43 59	.11724	.99310	.06909	.99699	.92790	.83864	8.5
9	6 21 35	.11077	.99385	.04442	.99732	.95289	.78915	9
9.5	6 01 32	.10497	.99448	9.02107	.99759	.97652	.74232	9.5
10	5 43 29	.09975	.99501	8.99891	.99783	10.99892	.69788	10
10.5	5 27 09	.09502	.99548	.97781	.99803	11.02021	.65560	10.5
11	5 12 18	.09072	.99588	.95770	.99820	.04050	.61528	11
11.5	4 58 45	.08679	.99623	.93848	.99836	.05987	.57676	11.5
12	4 46 19	.08319	.99653	8.92007	9.98849	11.07842	7.53986	12

TABLE IV.—ELEMENTS OF TRANSITION CURVES.

Point.	Total Central Angle φ	Nat. sin φ	Nat. cos φ	Log sin φ	Log cos φ	Log vers φ	x	Log x	y
1	0° 07' 30"	.0022	one	7.33878	10.00000	4.37654	0.027	8.43568	25.000
2	0 22 30	.0063	one	7.81590	9.99999	5.33078	0.136	9.13463	50.000
3	0 45 00	.0131	.9999	8.11692	9.99996	5.93284	0.382	9.58181	74.999
4	1 15 00	.0218	.9997	8.33873	9.99989	6.37653	0.818	9.91280	99.995
5	1 52 30	.0327	.9994	8.51480	9.99976	6.72869	1.500	0.17602	124.985
6	2 37 30	.0458	.9989	8.66083	9.99954	7.02091	2.481	0.39467	149.966
7	3 30 00	.0610	.9981	8.78567	9.99919	7.27072	3.817	0.58171	174.930
8	4 30 00	.0784	.9969	8.89464	9.99866	7.48892	5.561	0.74514	199.870
9	5 37 30	.0980	.9952	8.99130	9.99790	7.68262	7.792	0.89164	224.772
10	6 52 30	.1197	.9928	9.07810	9.99686	7.85675	10.489	1.02061	249.623

0° 30'-per-25-feet spiral.

— sighting at —		Deflections from the tangent at the point occupied when the instrument is at—									
Q	1	2	3	4	5	6	7	8	9	10	
0° 0' 0"	0° 3' 45"	0° 13' 07"	0° 27' 30"	0° 46' 52"	1° 11' 15"	1° 40' 37"	2° 15' 00"	2° 54' 22"	3° 38' 45"	4° 28' 10"	
0 3 45	0 0 00	0 07 30	0 20 37	0 38 45	1 01 52	1 30 00	2 03 07	2 41 15	3 24 22	4 12 30	
0 9 22	0 7 30	0 00 00	0 11 15	0 28 07	0 50 00	1 16 52	1 48 45	2 25 37	3 07 30	3 54 22	
0 17 30	0 16 52	0 11 15	0 00 00	0 15 00	0 35 37	1 01 15	1 31 52	2 07 30	2 48 07	3 33 45	
0 28 07	0 28 45	0 24 22	0 15 00	0 00 00	0 18 45	0 43 07	1 12 30	1 46 52	2 26 15	3 10 37	
0 41 15	0 43 07	0 40 00	0 31 52	0 18 45	0 00 00	0 22 30	0 50 37	1 23 45	2 01 52	2 45 00	
0 56 52	1 00 00	0 58 07	0 51 15	0 39 22	0 22 30	0 00 00	0 26 15	0 58 07	1 35 00	2 16 52	
1 15 00	1 19 22	1 18 45	1 13 07	1 02 30	0 46 52	0 26 15	0 00 00	0 30 00	1 05 37	1 46 15	
1 35 37	1 41 15	1 41 52	1 37 30	1 28 07	1 13 45	0 54 22	0 30 00	0 00 00	0 33 45	1 13 07	
1 58 45	2 05 37	2 07 30	2 04 22	1 56 15	1 43 07	1 25 00	1 01 52	0 33 45	0 00 00	0 37 30	
2 24 30	2 37 30	2 35 37	2 33 45	2 26 52	2 15 00	1 58 07	1 36 15	1 09 22	0 37 30	0 00 00	

TABLE IV.—ELEMENTS OF TRANSITION CURVES.

Point.	Total Central Angle φ	Nat. sin φ	Nat. cos φ	Log sin φ	Log cos φ	Log vers φ	x	Log x	y
1	0° 15'	.0043	one	7.63981	9.99999	4.97866	.055	8.73672	25.000
2	0 45	.0131	.9999	8.11692	9.99996	5.93284	.273	9.43616	49.999
3	1 30	.0262	.9996	8.41792	9.99985	6.53488	.763	9.88252	74.994
4	2 30	.0436	.9996	8.63968	9.99958	6.97853	1.636	0.21378	99.979
5	3 45	.0654	.9978	8.81560	9.99907	7.33063	2.999	0.47697	124.942
6	5 15	.0915	.9958	8.96143	9.99817	7.62274	4.960	0.69548	149.865
7	7 00	.1218	.9925	9.08589	9.99675	7.87238	7.628	0.88241	174.722
8	9 00	.1564	.9877	9.19433	9.99462	8.09031	11.107	1.04559	199.479
9	11 15	.1951	.9808	9.29023	9.99157	8.28363	15.502	1.19039	224.090
10	13 45	.2377	.9713	9.37606	9.98737	8.45724	20.913	1.32041	248.497

1°-per-25-foot spiral.

Deflections from the tangent at the point occupied when the instrument is at—

	Q	1	2	3	4	5	6	7	8	9	10
Q	0° 0' 0"	0° 07' 30"	0° 26' 15"	0° 55' 0"	1° 33' 45"	2° 22' 30"	3° 21' 15"	4° 30' 00"	5° 48' 47"	7° 17' 34"	8° 56' 22"
1	0 07 30	0 00 00	0 15 00	0 41 15	1 17 30	2 03 45	3 00 00	4 06 15	5 22 30	6 48 47	8 25 05
2	0 18 45	0 15 00	0 00 00	0 22 30	0 56 15	1 40 00	2 33 45	3 37 30	4 51 15	6 15 02	7 48 49
3	0 35 00	0 33 45	0 22 30	0 00 00	0 30 00	1 11 15	2 02 30	3 03 45	4 15 00	5 36 15	7 07 32
4	0 56 15	0 57 30	0 48 45	0 30 00	0 00 00	0 37 30	1 26 15	2 25 00	3 33 45	4 52 30	6 21 17
5	1 22 30	1 26 15	1 20 00	1 03 45	0 37 30	0 00 00	0 45 00	1 41 15	2 47 30	4 03 45	5 30 00
6	1 53 45	2 00 00	1 56 15	1 42 30	1 18 45	0 45 00	0 00 00	1 52 30	1 56 15	3 10 00	4 33 45
7	2 30 00	2 38 45	2 37 30	2 26 15	2 05 00	1 33 45	0 52 30	0 00 00	1 00 00	2 11 15	3 32 30
8	3 11 13	3 22 30	3 23 45	3 15 00	2 56 15	2 27 30	1 48 45	1 00 00	0 00 00	1 07 30	2 26 15
9	3 57 26	4 11 13	4 14 58	4 08 45	3 52 30	3 26 15	2 50 00	2 03 45	1 07 30	0 00 00	1 15 00
10	4 48 38	5 04 55	5 11 11	5 07 28	4 53 43	4 30 00	3 56 15	3 12 30	2 18 45	1 15 00	0 00 00

TABLE IV.—ELEMENTS OF TRANSITION CURVES.

Point.	Total Central Angle φ	Nat. sin φ	Nat. cos φ	Log sin φ	Log cos φ	Log vers φ	Σ	Log x	ν
1	0° 30'	.0087	.9999	7.94084	9.99998	5.58066	0.109	9.03774	25.000
2	1 30	.0262	.9996	8.41792	9.99985	6.53488	0.545	9.73676	49.996
3	3 00	.0523	.9986	8.71880	9.99946	7.13687	1.527	0.18388	74.977
4	5 00	.0871	.9962	8.94029	9.99834	7.58039	3.271	0.51468	99.916
5	7 30	.1303	.9914	9.11570	9.99627	7.93222	5.992	0.77762	124.767
6	10 30	.1822	.9832	9.26063	9.99266	8.22389	9.903	0.99579	149.459
7	14 00	.2419	.9703	9.38367	9.98696	8.47282	15.208	1.18207	173.890
8	18 00	.3090	.9516	9.48998	9.97826	8.68969	22.099	1.34437	197.922
9	22 30	.3827	.9239	9.58284	9.96561	8.88150	30.752	1.48787	221.376
10	27 30	.4617	.8870	9.66446	9.94793	9.05303	41.317	1.61613	244.034

2°-per-25-foot spiral.

sighting
at

Q

1

2

3

4

5

6

7

8

9

10

Deflections from the tangent at the point occupied when the instrument is at—

Q

1

2

3

4

5

6

7

8

9

10

0° 00' 00"

0 15 00

0 37 30

1 10 00

1 52 30

2 45 00

3 47 28

4 59 53

6 22 15

7 54 30

9 36 35

0° 15' 00"

0 00 00

0 30 00

1 07 30

1 55 00

2 52 30

3 59 59

5 17 26

6 44 50

8 22 08

10 00 17

0° 52' 30"

0 30 00

0 00 00

0 45 00

1 37 30

2 40 00

3 52 30

5 14 58

6 47 24

8 29 45

10 22 00

1° 50' 00"

1 22 30

0 45 00

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1 00 00

2 07 30

3 25 00

4 52 30

6 29 56

8 17 21

10 14 40

3° 07' 30"

2 35 00

1 52 30

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1 15 00

2 37 30

4 10 00

5 52 30

7 44 55

9 47 18

4° 45' 00"

4 07 30

3 20 00

2 22 30

1 15 00

0 00 00

1 30 00

3 07 30

4 55 00

6 52 30

8 59 54

6° 42' 30"

6 00 01

5 07 30

4 05 00

2 52 30

1 30 00

0 00 00

1 45 00

3 37 30

5 40 00

7 52 30

9° 00' 05"

8 12 34

7 15 02

6 07 30

4 50 00

3 22 30

1 45 00

0 00 00

2 00 00

4 07 30

6 25 00

11° 37' 45"

10 45 10

9 42 36

8 30 04

7 07 30

5 35 00

3 52 30

2 00 00

0 00 00

2 15 00

4 37 30

14° 35' 30"

13 37 52

12 30 15

11 12 39

9 45 05

8 07 30

6 20 00

4 22 30

2 15 00

0 00 00

2 30 00

17° 53' 25"

16 50 42

15 38 00

14 15 20

12 42 42

11 00 06

9 07 30

7 05 00

4 52 30

2 30 00

0 00 00

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
100	00 000	043	087	130	173	216	260	303	346	389	
101	432	475	518	561	604	646	689	732	775	817	
102	860	902	945	987	*030	*072	*114	*157	*199	*241	43 43 42 41
103	01 283	326	368	410	452	494	536	578	619	661	.1 4.3 4.3 4.2 4.1
104	703	745	787	828	870	911	953	994	*036	*077	.2 8.7 8.6 8.4 8.2
105	02 119	160	201	243	284	325	366	407	448	489	.3 13.0 12.9 12.6 12.3
106	530	571	612	653	694	735	775	816	857	898	.4 17.4 17.2 16.8 16.4
107	938	979	*019	*060	*100	*141	*181	*221	*262	*302	.5 21.7 21.5 21.0 20.5
108	03 342	382	422	463	503	543	583	623	663	703	.6 26.1 25.8 25.2 24.6
109	742	782	822	862	901	941	981	*020	*060	*100	.7 30.4 30.1 29.4 28.7
110	04 139	178	218	257	297	336	375	415	454	493	.8 34.8 34.4 33.6 32.8
111	532	571	610	649	688	727	766	805	844	883	.9 39.1 38.7 37.8 36.9
112	922	960	999	*038	*076	*115	*154	*192	*231	*269	
113	05 308	346	384	423	461	499	538	576	614	652	48 40 39 38
114	690	728	766	804	842	880	918	956	994	*032	.1 4.6 4.0 3.9 3.8
115	06 070	107	145	183	220	258	296	333	371	408	.2 8.1 8.0 7.8 7.6
116	446	483	520	558	595	632	670	707	744	781	.3 12.1 12.0 11.7 11.4
117	818	855	893	930	967	*004	*040	*077	*114	*151	.4 16.2 16.0 15.6 15.2
118	07 188	225	261	298	335	372	408	445	481	518	.5 20.2 20.0 19.5 19.0
119	554	591	627	664	700	737	773	809	845	882	.6 24.3 24.0 23.4 22.8
120	918	954	990	*026	*062	*098	*134	*170	*206	*242	.7 28.3 28.0 27.3 26.6
121	08 278	314	350	386	422	457	493	529	564	600	.8 32.4 32.0 31.2 30.4
122	636	671	707	742	778	813	849	884	920	955	.9 36.4 36.0 35.1 34.2
123	990	*026	*061	*096	*131	*166	*202	*237	*272	*307	
124	09 342	377	412	447	482	517	552	586	621	656	37 37 36 35
125	691	725	760	795	830	864	899	933	968	*002	.1 3.7 3.7 3.6 3.5
126	10 037	071	106	140	174	209	243	277	312	346	.2 7.5 7.4 7.2 7.0
127	380	414	448	483	517	551	585	619	653	687	.3 11.2 11.1 10.8 10.5
128	721	755	789	822	856	890	924	958	991	*025	.4 15.0 14.8 14.4 14.0
129	11 059	092	126	160	193	227	260	294	327	361	.5 18.7 18.5 18.0 17.5
130	394	427	461	494	528	561	594	627	661	694	.6 22.5 22.2 21.6 21.0
131	727	760	793	826	859	892	925	958	991	*024	.7 26.2 25.9 25.2 24.5
132	12 057	090	123	156	189	221	254	287	320	352	.8 30.0 29.6 28.8 28.0
133	385	418	450	483	515	548	580	613	645	678	.9 33.7 33.3 32.4 31.5
134	710	743	775	807	840	872	904	937	969	*001	
135	13 033	065	097	130	162	194	226	258	290	322	34 34 33 32
136	354	386	417	449	481	513	545	577	608	640	.1 3.4 3.4 3.3 3.2
137	672	703	735	767	798	830	862	893	925	956	.2 6.9 6.8 6.6 6.4
138	988	*019	*051	*082	*113	*145	*176	*207	*239	*270	.3 10.3 10.2 9.9 9.6
139	14 301	332	364	395	426	457	488	519	550	582	.4 13.8 13.6 13.2 12.8
140	613	644	675	706	736	767	798	829	860	891	.5 17.2 17.0 16.5 16.0
141	922	952	983	*014	*045	*075	*106	*137	*167	*198	.6 20.7 20.4 19.8 19.2
142	15 229	259	290	320	351	381	412	442	473	503	.7 24.1 23.8 23.1 22.4
143	533	564	594	624	655	685	715	745	776	806	.8 27.6 27.2 26.4 25.6
144	836	866	896	926	956	987	*017	*047	*077	*107	.9 31.0 30.6 29.7 28.8
145	16 137	166	196	226	256	286	316	346	376	405	
146	435	465	494	524	554	584	613	643	672	702	31 31 30 29
147	731	761	791	820	849	879	908	938	967	997	.1 3.1 3.1 3.0 2.9
148	17 026	055	085	114	143	172	202	231	260	289	.2 6.3 6.2 6.0 5.8
149	318	348	377	406	435	464	493	522	551	580	.3 9.4 9.3 9.0 8.7
150	609	638	667	696	725	753	782	811	840	869	.4 12.6 12.4 12.0 11.6
											.5 15.7 15.5 15.0 14.5
											.6 18.9 18.6 18.0 17.4
											.7 22.0 21.7 21.0 20.3
											.8 25.2 24.8 24.0 23.2
											.9 28.3 27.9 27.0 26.1
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
150	17 609	638	667	696	725	753	782	811	840	869	
151	897	926	955	984	*012	*041	*070	*098	*127	*156	29 28 27
152	18 184	213	241	270	298	327	355	384	412	440	.1 2.9 2.8 2.7
153	469	497	526	554	582	611	639	667	695	724	.2 5.8 5.6 5.4
154	752	780	808	836	864	893	921	949	977	*005	.3 8.7 8.4 8.1
155	19 033	061	089	117	145	173	201	229	256	284	.4 11.6 11.2 10.8
156	312	340	368	396	423	451	479	507	534	562	.5 14.5 14.0 13.5
157	590	617	645	673	700	728	755	783	810	838	.6 17.4 16.8 16.2
158	865	893	920	948	975	*003	*030	*057	*085	*112	.7 20.3 19.6 18.9
159	20 139	167	194	221	249	276	303	330	357	385	.8 23.2 22.4 21.6
160	412	439	466	493	520	547	574	601	628	655	.9 26.1 25.2 24.3
161	682	709	736	763	790	817	844	871	898	924	
162	951	978	*005	*032	*058	*085	*112	*139	*165	*192	26 26
163	21 219	245	272	298	325	352	378	405	431	458	.1 2.6 2.6
164	484	511	537	564	590	616	643	669	695	722	.2 5.3 5.3
165	748	774	801	827	853	880	906	932	958	984	.3 7.9 7.8
166	22 011	037	063	089	115	141	167	193	219	245	.4 10.6 10.4
167	271	297	323	349	375	401	427	453	479	505	.5 13.3 13.0
168	531	557	582	608	634	660	686	711	737	763	.6 15.9 15.6
169	788	814	840	865	891	917	942	968	994	*019	.7 18.5 18.2
170	23 045	070	096	121	147	172	198	223	249	274	.8 21.2 20.8
171	299	325	350	375	401	426	451	477	502	527	.9 23.8 23.4
172	553	578	603	628	653	679	704	729	754	779	
173	804	829	855	880	905	930	955	980	*005	*030	25 25 24
174	24 055	080	105	129	154	179	204	229	254	279	.1 2.5 2.5 2.4
175	304	328	353	378	403	427	452	477	502	526	.2 5.1 5.0 4.8
176	551	576	600	625	650	674	699	723	748	773	.3 7.6 7.5 7.2
177	797	822	846	871	895	920	944	968	993	*017	.4 10.2 10.0 9.6
178	25 042	066	091	115	139	164	188	212	237	261	.5 12.7 12.5 12.0
179	285	309	334	358	382	406	430	455	479	503	.6 15.3 15.0 14.4
180	527	551	575	599	623	647	672	696	720	744	.7 17.8 17.5 16.8
181	768	792	816	840	863	887	911	935	959	983	.8 20.4 20.0 19.2
182	26 007	031	055	078	102	126	150	174	197	221	.9 22.9 22.5 21.6
183	245	269	292	316	340	363	387	411	434	458	
184	482	505	529	552	576	599	623	646	670	693	23 23
185	717	740	764	787	811	834	858	881	904	928	.1 2.3 2.3
186	951	974	998	*021	*044	*068	*091	*114	*137	*161	.2 4.7 4.6
187	27 184	207	230	254	277	300	323	346	369	392	.3 7.0 6.9
188	416	439	462	485	508	531	554	577	600	623	.4 9.4 9.2
189	646	669	692	715	738	761	784	806	829	852	.5 11.7 11.5
190	875	898	921	944	966	989	*012	*035	*058	*080	.6 14.1 13.8
191	28 103	126	149	171	194	217	239	262	285	307	.7 16.4 16.1
192	330	352	375	398	420	443	465	488	510	533	.8 18.8 18.4
193	555	578	600	623	645	668	690	713	735	758	.9 21.1 20.7
194	780	802	825	847	869	892	914	936	959	981	
195	29 003	025	048	070	092	114	137	159	181	203	22 22 21
196	225	248	270	292	314	336	358	380	402	424	.1 2.2 2.2 2.1
197	446	468	490	512	534	556	578	600	622	644	.2 4.5 4.4 4.3
198	666	688	710	732	754	776	798	820	841	863	.3 6.7 6.6 6.4
199	885	907	929	950	972	994	*016	*038	*059	*081	.4 9.0 8.6 8.4
200	30 103	124	146	168	190	211	233	254	276	298	.5 11.2 11.0 10.6
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
200	30 103	124	146	168	190	211	233	254	276	298		
201		319	341	363	384	406	427	449	470	492	22	21
202		535	556	578	599	621	642	664	685	707	.1	2.2
203		749	771	792	813	835	856	878	899	920	.2	4.4
204		963	984	*005	*027	*048	*069	*090	*112	*133	.3	6.6
205	31 175	196	217	239	260	281	302	323	344	365	.4	8.8
206		386	408	429	450	471	492	513	534	555	.5	11.0
207		597	618	639	660	681	702	722	743	764	.6	13.2
208		806	827	848	869	890	910	931	952	973	.7	15.4
209	32 014	035	056	077	097	118	139	160	180	201	.8	17.6
210		222	242	263	284	304	325	346	366	387	.9	19.8
211		428	449	469	490	510	531	551	572	592	26	20
212		633	654	674	695	715	736	756	776	797	.1	2.0
213		838	858	878	899	919	940	960	980	*001	.2	4.1
214	33 041	061	082	102	122	142	163	183	203	223	.3	6.1
215		244	264	284	304	324	344	365	385	405	.4	8.2
216		445	465	485	505	525	546	566	586	606	.5	10.2
217		646	666	686	706	726	746	766	786	806	.6	12.3
218		845	865	885	905	925	945	965	985	*004	.7	14.3
219	34 044	064	084	104	123	143	163	183	203	222	.8	16.4
220		242	262	281	301	321	341	360	380	400	.9	18.4
221		439	459	478	498	518	537	557	576	596	16	19
222		635	655	674	694	713	733	752	772	791	.1	1.9
223		830	850	869	889	908	928	947	966	986	.2	3.9
224	35 025	044	063	083	102	121	141	160	179	199	.3	5.8
225		218	237	257	276	295	314	334	353	372	.4	7.8
226		411	430	449	468	487	507	526	545	564	.5	9.7
227		602	621	641	660	679	698	717	736	755	.6	11.7
228		793	812	831	850	869	888	907	926	945	.7	13.6
229		983	*002	*021	*040	*059	*078	*097	*116	*135	.8	15.6
230	36 173	191	210	229	248	267	286	305	323	342	.9	17.5
231		361	380	399	417	436	455	474	492	511	18	18
232		549	567	586	605	623	642	661	679	698	.1	1.8
233		735	754	773	791	810	828	847	866	884	.2	3.7
234		921	940	958	977	996	*014	*033	*051	*070	.3	5.5
235	37 107	125	143	162	180	199	217	236	254	273	.4	7.4
236		291	309	328	346	364	383	401	420	438	.5	9.2
237		475	493	511	530	548	566	584	603	621	.6	11.1
238		657	676	694	712	730	749	767	785	803	.7	12.9
239		840	858	876	894	912	930	948	967	985	.8	14.8
240	38 021	039	057	075	093	111	129	147	165	183	.9	16.6
241		201	219	237	255	273	291	309	327	345	17	17
242		381	399	417	435	453	471	489	507	525	.1	1.7
243		560	578	596	614	632	650	667	685	703	.2	3.5
244		739	757	774	792	810	828	845	863	881	.3	5.2
245		916	934	952	970	987	*005	*023	*040	*058	.4	7.0
246	39 093	111	129	146	164	181	199	217	234	252	.5	8.7
247		269	287	305	322	340	357	375	392	410	.6	10.5
248		445	462	480	497	515	532	550	567	585	.7	12.2
249		620	637	655	672	689	707	724	742	759	.8	14.0
250		794	811	828	846	863	881	898	915	933	.9	15.7
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.		
250	39 794	81î	828	846	863	881	898	915	933	950			
251	967	984	*002	*019	*036	*054	*071	*088	*105	*123			
252	40 140	157	174	191	209	226	243	260	277	295			
253	312	329	346	363	380	398	415	432	449	466	17 17		
254	483	500	517	534	551	569	586	603	620	637	.1	1.7	1.7
255	654	671	688	705	722	739	756	773	790	807	.2	3.5	3.4
256	824	841	858	875	892	908	925	942	959	976	.3	5.2	5.1
257	993	*010	*027	*044	*061	*077	*094	*111	*128	*145	.4	7.0	6.8
258	41 162	179	195	212	229	246	263	279	296	313	.5	8.7	8.5
259	330	346	363	380	397	413	430	447	464	480	.6	10.5	10.2
260	497	514	530	547	564	581	597	614	631	647	.7	12.2	11.9
261	664	680	697	714	730	747	764	780	797	813	.8	14.0	13.6
262	830	846	863	880	896	913	929	946	962	979	.9	15.7	15.3
263	995	*012	*028	*045	*061	*078	*094	*111	*127	*144			
264	42 160	177	193	209	226	242	259	275	292	308	16 16		
265	324	341	357	373	390	406	423	439	455	472			
266	488	504	521	537	553	569	586	602	618	635	.1	1.6	1.6
267	651	667	683	700	716	732	748	765	781	797	.2	3.3	3.2
268	813	829	846	862	878	894	910	927	943	959	.3	4.9	4.8
269	975	991	*007	*023	*040	*056	*072	*088	*104	*120	.4	6.6	6.4
270	43 136	152	168	184	200	216	233	249	265	281	.5	8.2	8.0
271	297	313	329	345	361	377	393	409	425	441	.6	9.9	9.6
272	457	473	489	505	520	536	552	568	584	600	.7	11.5	11.2
273	616	632	648	664	680	695	711	727	743	759	.8	13.2	12.8
274	775	791	806	822	838	854	870	886	901	917	.9	14.8	14.4
275	933	949	965	980	996	*012	*028	*043	*059	*075			
276	44 091	106	122	138	154	169	185	201	216	232	15 15		
277	248	263	279	295	310	326	342	357	373	389	.1	1.5	1.5
278	404	420	435	451	467	482	498	513	529	545	.2	3.1	3.0
279	560	576	591	607	622	638	653	669	685	700	.3	4.6	4.5
280	716	731	747	762	778	793	809	824	839	855	.4	6.2	6.0
281	870	886	901	917	932	948	963	978	994	*009	.5	7.7	7.5
282	45 025	040	055	071	086	102	117	132	148	163	.6	9.3	9.0
283	178	194	209	224	240	255	270	286	301	316	.7	10.8	10.5
284	332	347	362	377	393	408	423	438	454	469	.8	12.4	12.0
285	484	499	515	530	545	560	576	591	606	621	.9	13.9	13.5
286	636	652	667	682	697	712	727	743	758	773			
287	788	803	818	833	848	864	879	894	909	924			
288	939	954	969	984	999	*014	*029	*044	*059	*075	14 14		
289	46 090	105	120	135	150	165	180	195	210	225	.1	1.4	1.4
290	240	255	269	284	299	314	329	344	359	374	.2	2.9	2.8
291	389	404	419	434	449	464	479	493	508	523	.3	4.3	4.2
292	538	553	568	583	597	612	627	642	657	672	.4	5.8	5.6
293	687	701	716	731	746	761	775	790	805	820	.5	7.2	7.0
294	834	849	864	879	894	908	923	938	952	967	.6	8.7	8.4
295	982	997	*011	*026	*041	*055	*070	*085	*100	*114	.7	10.1	9.8
296	47 129	144	158	173	188	202	217	232	246	261	.8	11.6	11.2
297	275	290	305	319	334	348	363	378	392	407	.9	13.0	12.6
298	421	436	451	465	480	494	509	523	538	552			
299	567	581	596	610	625	639	654	668	683	697			
300	712	726	741	755	770	784	799	813	828	842			
N.	0	1	2	3	4	5	6	7	8	9	P. P.		

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.		
800	47 712	726	741	755	770	784	799	813	828	842			
301	856	871	885	900	914	928	943	957	972	986			
302	48 000	015	029	044	058	072	087	101	115	130			
303	144	158	173	187	201	216	230	244	259	273			
304	287	301	316	330	344	358	373	387	401	415			
305	430	444	458	472	487	501	515	529	543	558			
306	572	586	600	614	629	643	657	671	685	699			
307	714	728	742	756	770	784	798	812	827	841			
308	855	869	883	897	911	925	939	953	967	982			
309	996	*010	*024	*038	*052	*066	*080	*094	*108	*122			
810	49 136	150	164	178	192	206	220	234	248	262			
311	276	290	304	318	332	346	359	373	387	401			
312	415	429	443	457	471	485	499	513	526	540			
313	554	568	582	596	610	624	637	651	665	679			
314	693	707	720	734	748	762	776	789	803	817			
315	831	845	858	872	886	900	913	927	941	955			
316	968	982	996	*010	*023	*037	*051	*065	*078	*092			
317	50 106	119	133	147	160	174	188	201	215	229			
318	242	256	270	283	297	311	324	338	352	365			
319	379	392	406	420	433	447	460	474	488	501			
820	515	528	542	555	569	583	596	610	623	637			
321	650	664	677	691	704	718	731	745	758	772			
322	785	799	812	826	839	853	866	880	893	907			
323	920	933	947	960	974	987	*001	*014	*027	*041			
324	51 054	068	081	094	108	121	135	148	161	175			
325	188	201	215	228	242	255	268	282	295	308			
326	322	335	348	361	375	388	401	415	428	441			
327	455	468	481	494	508	521	534	547	561	574			
328	587	600	614	627	640	653	667	680	693	706			
329	719	733	746	759	772	785	798	812	825	838			
830	851	864	877	891	904	917	930	943	956	969			
331	983	996	*009	*022	*035	*048	*061	*074	*087	*100			
332	52 114	127	140	153	166	179	192	205	218	231			
333	244	257	270	283	296	309	322	335	348	361			
334	374	387	400	413	426	439	452	465	478	491			
335	504	517	530	543	556	569	582	595	608	621			
336	634	647	660	672	685	698	711	724	737	750			
337	763	776	789	801	814	827	840	853	866	879			
338	891	904	917	930	943	956	968	981	994	*007			
339	53 020	033	045	058	071	084	097	109	122	135			
840	148	160	173	186	199	211	224	237	250	262			
341	275	288	301	313	326	339	352	364	377	390			
342	402	415	428	440	453	466	478	491	504	516			
343	529	542	554	567	580	592	605	618	630	643			
344	656	668	681	693	706	719	731	744	756	769			
345	782	794	807	819	832	845	857	870	882	895			
346	907	920	932	945	958	970	983	995	*008	*020			
347	54 033	045	058	070	083	095	108	120	133	145			
348	158	170	183	195	208	220	232	245	257	270			
349	282	295	307	320	332	344	357	369	382	394			
850	407	419	431	444	456	469	481	493	506	518			

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
850	54 407	419	431	444	456	469	481	493	506	518		12
351	530	543	555	568	580	592	605	617	629	642	.1	1.2
352	654	666	679	691	703	716	728	740	753	765	.2	2.5
353	777	790	802	814	826	839	851	863	876	888	.3	3.7
354	900	912	925	937	949	961	974	986	998	*010	.4	5.0
355	55 023	035	047	059	071	084	096	108	120	133	.5	6.2
356	145	157	169	181	194	206	218	230	242	254	.6	7.5
357	267	279	291	303	315	327	340	352	364	376	.7	8.7
358	388	400	412	424	437	449	461	473	485	497	.8	10.0
359	509	521	533	545	558	570	582	594	606	618	.9	11.2
860	630	642	654	666	678	690	702	714	726	738		12
361	750	762	775	787	799	811	823	835	847	859	.1	1.2
362	871	883	895	907	919	931	943	955	966	978	.2	2.4
363	990	*002	*014	*026	*038	*050	*062	*074	*086	*098	.3	3.6
364	56 110	122	134	146	158	170	181	193	205	217	.4	4.8
365	229	241	253	265	277	288	300	312	324	336	.5	6.0
366	348	360	372	383	395	407	419	431	443	455	.6	7.2
367	466	478	490	502	514	525	537	549	561	573	.7	8.4
368	585	596	608	620	632	643	655	667	679	691	.8	9.6
369	702	714	726	738	749	761	773	785	796	808	.9	10.8
870	820	832	843	855	867	879	890	902	914	925		11
371	937	949	961	972	984	996	*007	*019	*031	*042	.1	1.1
372	57 054	066	077	089	101	112	124	136	147	159	.2	2.3
373	171	182	194	206	217	229	240	252	264	275	.3	3.4
374	287	299	310	322	333	345	357	368	380	391	.4	4.6
375	403	414	426	438	449	461	472	484	495	507	.5	5.7
376	519	530	542	553	565	576	588	599	611	622	.6	6.9
377	634	645	657	668	680	691	703	714	726	737	.7	8.0
378	749	760	772	783	795	806	818	829	841	852	.8	9.2
379	864	875	887	898	909	921	932	944	955	967	.9	10.3
880	978	990	*001	*012	*024	*035	*047	*058	*069	*081		11
381	58 092	104	115	126	138	149	161	172	183	195	.1	1.1
382	206	217	229	240	252	263	274	286	297	308	.2	2.2
383	320	331	342	354	365	376	388	399	410	422	.3	3.3
384	433	444	455	467	478	489	501	512	523	535	.4	4.4
385	546	557	568	580	591	602	613	625	636	647	.5	5.5
386	658	670	681	692	703	715	726	737	748	760	.6	6.6
387	771	782	793	804	816	827	838	849	861	872	.7	7.7
388	883	894	905	916	928	939	950	961	972	984	.8	8.8
389	995	*006	*017	*028	*039	*050	*062	*073	*084	*095	.9	9.9
890	59 106	117	128	140	151	162	173	184	195	206		10
391	217	229	240	251	262	273	284	295	306	317	.1	1.0
392	328	339	351	362	373	384	395	406	417	428	.2	2.1
393	439	450	461	472	483	494	505	516	527	538	.3	3.1
394	549	560	571	582	593	604	615	626	637	648	.4	4.2
395	659	670	681	692	703	714	725	736	747	758	.5	5.2
396	769	780	791	802	813	824	835	846	857	868	.6	6.3
397	879	890	901	912	923	933	944	955	966	977	.7	7.3
398	988	999	*010	*021	*032	*043	*053	*064	*075	*086	.8	8.4
399	60 097	108	119	130	141	151	162	173	184	195	.9	9.4
400	206	217	227	238	249	260	271	282	293	303		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
400	60 206	217	227	238	249	260	271	282	293	303		
401	314	325	336	347	357	368	379	390	401	412		
402	422	433	444	455	466	476	487	498	509	519		
403	530	541	552	563	573	584	595	606	616	627	II	
404	638	649	659	670	681	692	702	713	724	735	.1	1.1
405	745	756	767	777	788	799	810	820	831	842	.2	2.2
406	852	863	874	884	895	906	916	927	938	949	.3	3.3
407	959	970	981	991	*002	*013	*023	*034	*044	*055	.4	4.4
408	61 066	076	087	098	108	119	130	140	151	161	.5	5.5
409	172	183	193	204	215	225	236	246	257	268	.6	6.6
410	278	289	299	310	320	331	342	352	363	373	.7	7.7
411	384	394	405	416	426	437	447	458	468	479	.8	8.8
412	489	500	511	521	532	542	553	563	574	584	.9	9.9
413	595	605	616	626	637	647	658	668	679	689		
414	700	710	721	731	742	752	763	773	784	794		
415	805	815	825	836	846	857	867	878	888	899	10	
416	909	920	930	940	951	961	972	982	993	*003	.1	1.0
417	62 013	024	034	045	055	065	076	086	097	107	.2	2.1
418	117	128	138	149	159	169	180	190	200	211	.3	3.1
419	221	232	242	252	263	273	283	294	304	314	.4	4.2
420	325	335	345	356	366	376	387	397	407	418	.5	5.2
421	428	438	449	459	469	480	490	500	510	521	.6	6.3
422	531	541	552	562	572	582	593	603	613	624	.7	7.3
423	634	644	654	665	675	685	695	706	716	726	.8	8.4
424	736	747	757	767	777	788	798	808	818	828	.9	9.4
425	839	849	859	869	879	890	900	910	920	931		
426	941	951	961	971	981	992	*002	*012	*022	*032		
427	63 043	053	063	073	083	093	104	114	124	134	10	
428	144	154	164	175	185	195	205	215	225	235	.1	1.0
429	245	256	266	276	286	296	306	316	326	336	.2	2.0
430	347	357	367	377	387	397	407	417	427	437	.3	3.0
431	447	458	468	478	488	498	508	518	528	538	.4	4.0
432	548	558	568	578	588	598	608	618	628	639	.5	5.0
433	649	659	669	679	689	699	709	719	729	739	.6	6.0
434	749	759	769	779	789	799	809	819	829	839	.7	7.0
435	849	859	869	879	889	899	909	919	928	938	.8	8.0
436	948	958	968	978	988	998	*008	*018	*028	*038	.9	9.0
437	64 048	058	068	078	088	098	107	117	127	137		
438	147	157	167	177	187	197	207	217	226	236		
439	246	256	266	276	286	296	306	315	325	335	9	
440	345	355	365	375	384	394	404	414	424	434	.1	0.9
441	444	453	463	473	483	493	503	512	522	532	.2	1.9
442	542	552	562	571	581	591	601	611	621	630	.3	2.8
443	640	650	660	670	679	689	699	709	718	728	.4	3.8
444	738	748	758	767	777	787	797	806	816	826	.5	4.7
445	836	846	855	865	875	885	894	904	914	923	.6	5.7
446	933	943	953	962	972	982	992	*001	*011	*021	.7	6.6
447	65 031	040	050	060	069	079	089	098	108	118	.8	7.6
448	128	137	147	157	166	176	186	195	205	215	.9	8.5
449	224	234	244	253	263	273	282	292	302	311		
450	321	331	340	350	360	369	379	389	398	408		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
450	65 32î	33I	34ô	350	360	369	379	389	398	408		10 .1 1.0 .2 2.0 .3 3.0 .4 4.0 .5 5.0 .6 6.0 .7 7.0 .8 8.0 .9 9.0
451	41î	42î	437	446	456	466	475	485	494	504		
452	514	523	533	542	552	562	571	581	590	600		
453	610	619	629	638	648	657	667	677	686	696		
454	705	715	724	734	744	753	763	772	782	791		
455	801	810	820	830	839	849	858	868	877	887		
456	896	906	915	925	934	944	953	963	972	982		
457	99î	*001	*010	*020	*029	*039	*048	*058	*067	*077		
458	66 086	096	105	115	124	134	143	153	162	172		
459	18î	19ô	200	209	219	228	238	247	257	266		
460	276	285	294	304	313	323	332	342	351	360		9 .1 0.9 .2 1.9 .3 2.8 .4 3.8 .5 4.7 .6 5.7 .7 6.6 .8 7.6 .9 8.5
461	370	379	389	398	408	417	426	436	445	455		
462	464	473	483	492	502	511	520	530	539	548		
463	558	567	577	586	595	605	614	623	633	642		
464	652	661	670	680	689	698	708	717	726	736		
465	745	754	764	773	782	792	801	810	820	829		
466	838	848	857	866	876	885	894	904	913	922		
467	93î	94I	95ô	959	969	978	987	996	*006	*015		
468	67 024	034	043	052	061	071	080	089	099	108		
469	11î	126	136	145	154	163	173	182	191	200		
470	210	219	228	237	246	256	265	274	283	293		9 .1 0.9 .2 1.8 .3 2.7 .4 3.6 .5 4.5 .6 5.4 .7 6.3 .8 7.2 .9 8.1
471	302	31î	32ô	329	339	348	357	366	376	385		
472	394	403	412	422	431	440	449	458	467	477		
473	486	495	504	513	523	532	541	550	559	568		
474	578	587	596	605	614	623	633	642	651	660		
475	669	678	687	697	706	715	724	733	742	751		
476	760	770	779	788	797	806	815	824	833	842		
477	852	861	870	879	888	897	906	915	924	933		
478	943	952	961	970	979	988	997	*006	*015	*024		
479	68 033	042	051	060	070	079	088	097	106	115		
480	124	133	142	151	160	169	178	187	196	205		8 .1 0.8 .2 1.7 .3 2.5 .4 3.4 .5 4.2 .6 5.1 .7 5.9 .8 6.8 .9 7.6
481	214	223	232	241	250	259	268	277	286	295		
482	304	313	322	331	340	349	358	367	376	385		
483	394	403	412	421	430	439	448	457	466	475		
484	484	493	502	511	520	529	538	547	556	565		
485	574	583	592	601	610	619	628	637	646	654		
486	663	672	681	690	699	708	717	726	735	744		
487	753	762	770	779	788	797	806	815	824	833		
488	842	851	860	868	877	886	895	904	913	922		
489	931	940	948	957	966	975	984	993	*002	*010		
490	69 019	028	037	046	055	064	073	081	090	099		
491	108	117	126	134	143	152	161	170	179	187		
492	196	205	214	223	232	240	249	258	267	276		
493	284	293	302	311	320	328	337	346	355	364		
494	372	381	390	399	408	416	425	434	443	451		
495	460	469	478	487	495	504	513	522	530	539		
496	548	557	565	574	583	592	600	609	618	627		
497	635	644	653	662	670	679	688	697	705	714		
498	723	731	740	749	758	766	775	784	792	801		
499	810	819	827	836	845	853	862	871	879	888		
500	897	905	914	923	931	940	949	958	966	975		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

N.	0	1	2	3	4	5	6	7	8	9	P. P.			
500	69 897	905	914	923	931	940	949	958	966	975		9		
501	984	992	*001	*010	*018	*027	*036	*044	*053	*061				
502	70 070	079	087	096	105	113	122	131	139	148				
503	157	165	174	182	191	200	208	217	226	234				
504	243	251	260	269	277	286	294	303	312	320				
505	329	337	346	355	363	372	380	389	398	406				
506	415	423	432	441	449	458	466	475	483	492				
507	501	509	518	526	535	543	552	560	569	578				
508	586	595	603	612	620	629	637	646	654	663				
509	672	680	689	697	706	714	723	731	740	748				
510	757	765	774	782	791	799	808	816	825	833	.7	6.3		
511	842	850	859	867	876	884	893	901	910	918	.8	7.2		
512	927	935	944	952	961	969	978	986	995	*003	.9	8.1		
513	71 011	020	028	037	045	054	062	071	079	088		8		
514	096	105	113	121	130	138	147	155	164	172				
515	180	189	197	206	214	223	231	239	248	256				
516	265	273	282	290	298	307	315	324	332	340				
517	349	357	366	374	382	391	399	408	416	424				
518	433	441	449	458	466	475	483	491	500	508				
519	516	525	533	542	550	558	567	575	583	592				
520	600	608	617	625	633	642	650	659	667	675				
521	684	692	700	709	717	725	734	742	750	758			.7	5.0
522	767	775	783	792	800	808	817	825	833	842	.8	6.8		
523	850	858	867	875	883	891	900	908	916	925	.9	7.6		
524	933	941	949	958	966	974	983	991	999	*007		8		
525	72 016	024	032	040	049	057	065	074	082	090				
526	098	107	115	123	131	140	148	156	164	173				
527	181	189	197	206	214	222	230	238	247	255				
528	263	271	280	288	296	304	312	321	329	337				
529	345	354	362	370	378	386	395	403	411	419				
530	427	436	444	452	460	468	476	485	493	501				
531	509	517	526	534	542	550	558	566	575	583				
532	591	599	607	615	624	632	640	648	656	664				
533	672	681	689	697	705	713	721	729	738	746	.7	5.6		
534	754	762	770	778	786	795	803	811	819	827	.8	6.4		
535	835	843	851	859	868	876	884	892	900	908	.9	7.2		
536	916	924	932	941	949	957	965	973	981	989		9		
537	997	*005	*013	*021	*030	*038	*046	*054	*062	*070				
538	73 078	086	094	102	110	118	126	134	143	151				
539	159	167	175	183	191	199	207	215	223	231				
540	239	247	255	263	271	279	287	295	303	311				
541	319	328	336	344	352	360	368	376	384	392				
542	400	408	416	424	432	440	448	456	464	472				
543	480	488	496	504	512	520	528	536	544	552				
544	560	568	576	584	592	600	608	615	623	631				
545	639	647	655	663	671	679	687	695	703	711	.7	5.2		
546	719	727	735	743	751	759	767	775	783	791	.8	6.0		
547	798	806	814	822	830	838	846	854	862	870	.9	6.7		
548	878	886	894	902	909	917	925	933	941	949				
549	957	965	973	981	989	997	*004	*012	*020	*028				
550	74 036	044	052	060	068	075	083	091	099	107				
N.	0	1	2	3	4	5	6	7	8	9			P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
550	74 036̂	044	052	060	068	075̂	083̂	091̂	099̂	107̂		8
551	115	123	131	139	146̂	154̂	162̂	170̂	178	186		
552	194	202	209̂	217̂	225̂	233	241	249	257	264̂		
553	272̂	280̂	288	296	304	312	319̂	327̂	335̂	343		
554	351	359	366̂	374̂	382̂	390	398	406	413̂	421̂		
555	429̂	437	445	453	460̂	468̂	476	484	492	499̂		
556	507̂	515̂	523	531	538̂	546̂	554̂	562	570	577̂		
557	585̂	593̂	601	609	616̂	624̂	632̂	640	648	655̂		
558	663̂	671	679	687	694̂	702̂	710	718	725̂	733̂		
559	741	749	756̂	764̂	772	780	788	795̂	803̂	811		
560	819	826̂	834̂	842	850	857̂	865̂	873	881	888̂	.4	3.2
561	896̂	904	912	919̂	927	935	942̂	950̂	958	966	.5	4.0
562	973̂	981̂	989	997	*004̂	*012̂	*020	*027̂	*035̂	*043	.6	4.8
563	75 051	058̂	066̂	074	081̂	089̂	097	105	112̂	120	.7	5.6
564	128	135̂	143̂	151	158̂	166̂	174	182	189̂	197	.8	6.4
565	205	212̂	220	228	235̂	243̂	251	258̂	266̂	274	.9	7.2
566	281̂	289̂	297	304̂	312̂	320	327̂	335̂	343	350̂		
567	358̂	366	373̂	381̂	389	396̂	404	412	419̂	427		
568	435	442̂	450̂	458	465̂	473	480̂	488̂	496	503̂		
569	511	519	526̂	534	541̂	549̂	557	564̂	572	580		
570	587̂	595	602̂	610̂	618	625̂	633	641	648̂	656		
571	663̂	671	679	686̂	694	701̂	709	717	724̂	732		7
572	739̂	747	755	762̂	770	777̂	785	792̂	800̂	808		
573	815̂	823	830̂	838	846	853̂	861	868̂	876	883̂		
574	891	899	906̂	914	921̂	929	936̂	944	951̂	959		
575	967	974̂	982	989̂	997	*004̂	*012̂	*019̂	*027̂	*034̂		
576	76 042	050	057̂	065	072̂	080	087̂	095	102̂	110		
577	117̂	125	132̂	140	147̂	155	162̂	170	178	185̂		
578	193	200̂	208	215̂	223	230̂	238	245̂	253	260̂		
579	268	275̂	283	290̂	298	305̂	313	320̂	328	335̂		
580	343	350̂	358	365̂	372̂	380	387̂	395	402̂	410		
581	417̂	425	432̂	440	447̂	455	462̂	470	477̂	485		
582	492̂	500	507	514̂	522	529̂	537	544̂	552	559̂		
583	567	574̂	582	589	596̂	604	611̂	619	626̂	634		
584	641̂	648̂	656	663̂	671	678̂	686	693̂	700̂	708		
585	715̂	723	730̂	738	745̂	752̂	760	767̂	775	782̂		
586	790	797	804̂	812	819̂	827	834	841̂	849	856̂		7
587	864	871	878̂	886	893̂	901	908	915̂	923	930̂		
588	937̂	945	952̂	960	967̂	974̂	982	989̂	997	*004̂		
589	77 011̂	019	026̂	033̂	041	048̂	055̂	063	070̂	078		
590	085̂	092̂	100	107̂	114̂	122	129̂	136̂	144	151̂		
591	158̂	166	173̂	181	188	195̂	203	210	217̂	225		
592	232	239̂	247	254	261̂	269	276	283̂	291	298		
593	305̂	313	320	327̂	335	342	349̂	356̂	364	371̂		
594	378̂	386	393̂	400̂	408	415	422̂	430	437	444̂		
595	451̂	459	466̂	473̂	481	488	495̂	503	510	517̂		
596	524̂	532	539	546̂	554	561	568̂	575̂	583	590		
597	597̂	604̂	612	619̂	626̂	634	641	648̂	655̂	663		
598	670	677̂	684̂	692	699	706̂	713̂	721	728	735̂		
599	742̂	750	757	764̂	771̂	779	786	793̂	800̂	808		
600	815	822̂	829̂	837	844	851̂	858̂	866	873	880	P. P.	
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
600	77 815	822	829	837	844	851	858	866	873	880		
601	887	894	902	909	916	923	931	938	945	952		
602	959	967	974	981	988	995	*003	*010	*017	*024		
603	78 031	039	046	053	060	067	075	082	089	096		
604	103	111	118	125	132	139	147	154	161	168		
605	175	182	190	197	204	211	218	226	233	240		
606	247	254	261	269	276	283	290	297	304	311	7	
607	319	326	333	340	347	354	362	369	376	383	.1	0.7
608	390	397	404	412	419	426	433	440	447	454	.2	1.5
609	461	469	476	483	490	497	504	511	518	526	.3	2.2
610	533	540	547	554	561	568	575	583	590	597	.4	3.0
611	604	611	618	625	632	639	646	654	661	668	.5	3.7
612	675	682	689	696	703	710	717	725	732	739	.6	4.5
613	746	753	760	767	774	781	788	795	802	810	.7	5.2
614	817	824	831	838	845	852	859	866	873	880	.8	6.0
615	887	894	901	908	915	923	930	937	944	951	.9	6.7
616	958	965	972	979	986	993	*000	*007	*014	*021		
617	79 028	035	042	049	056	063	070	078	085	092		
618	099	106	113	120	127	134	141	148	155	162		
619	169	176	183	190	197	204	211	218	225	232		
620	239	246	253	260	267	274	281	288	295	302		
621	309	316	323	330	337	344	351	358	365	372	7	
622	379	386	393	400	407	414	421	428	435	442	.1	0.7
623	449	456	462	469	476	483	490	497	504	511	.2	1.4
624	518	525	532	539	546	553	560	567	574	581	.3	2.1
625	588	595	602	609	616	622	629	636	643	650	.4	2.8
626	657	664	671	678	685	692	699	706	713	720	.5	3.5
627	727	733	740	747	754	761	768	775	782	789	.6	4.2
628	796	803	810	816	823	830	837	844	851	858	.7	4.9
629	865	872	879	886	892	899	906	913	920	927	.8	5.6
630	934	941	948	954	961	968	975	982	989	996	.9	6.3
631	80 003	010	016	023	030	037	044	051	058	065		
632	071	078	085	092	099	106	113	120	126	133		
633	140	147	154	161	168	174	181	188	195	202		
634	209	216	222	229	236	243	250	257	263	270		
635	277	284	291	298	304	311	318	325	332	339		
636	345	352	359	366	373	380	386	393	400	407	8	
637	414	421	427	434	441	448	455	461	468	475	.1	0.6
638	482	489	495	502	509	516	523	529	536	543	.2	1.3
639	550	557	563	570	577	584	591	597	604	611	.3	1.9
640	618	625	631	638	645	652	658	665	672	679	.4	2.6
641	686	692	699	706	713	719	726	733	740	746	.5	3.2
642	753	760	767	774	780	787	794	801	807	814	.6	3.9
643	821	828	834	841	848	855	862	868	875	882	.7	4.5
644	888	895	902	909	915	922	929	936	942	949	.8	5.2
645	956	962	969	976	983	989	996	*003	*010	*016	.9	5.8
646	81 023	030	036	043	050	057	063	070	077	083		
647	090	097	104	110	117	124	130	137	144	151		
648	157	164	171	177	184	191	197	204	211	218		
649	224	231	238	244	251	258	264	271	278	284		
650	291	298	304	311	318	324	331	338	345	351		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
650	81 29î	298	304	31î	318	324	33î	338	345	35î		
651	358	365	37î	378	385	39î	398	405	41î	418		
652	425	43î	438	444	45î	458	464	47î	478	484		
653	49î	498	504	51î	518	524	531	538	544	551		
654	558	564	571	577	584	591	597	604	611	617		
655	624	631	637	644	650	657	664	670	677	684		
656	690	697	703	710	717	723	730	736	743	750	7	
657	756	763	770	776	783	789	796	803	809	816	.1	0.7
658	822	829	836	842	849	855	862	869	875	882	.2	1.4
659	888	895	90î	908	915	92î	928	934	941	948	.3	2.1
660	954	961	967	974	980	987	994	*000	*007	*013	.4	2.8
661	82 020	026	033	040	046	053	059	066	072	079	.5	3.5
662	086	092	099	105	112	118	125	13î	138	145	.6	4.2
663	15î	158	164	171	177	184	190	197	203	210	.7	4.9
664	217	223	230	236	243	249	256	262	269	275	.8	5.6
665	282	288	295	302	308	315	32î	328	334	341	.9	6.3
666	347	354	360	367	373	380	386	393	399	406		
667	412	419	425	432	438	445	45î	458	464	471		
668	477	484	490	497	503	510	516	523	529	536		
669	542	549	555	562	568	575	58î	588	594	601		
670	607	614	620	627	633	640	646	653	659	666		
671	672	678	685	69î	698	704	711	717	724	730	8	
672	737	743	750	756	763	769	775	782	788	795	.1	0.6
673	80î	808	814	821	827	834	840	846	853	859	.2	1.3
674	866	872	879	885	892	898	904	911	917	924	.3	1.9
675	930	937	943	949	956	962	969	975	982	988	.4	2.6
676	994	*001	*007	*014	*020	*027	*033	*039	*046	*052	.5	3.2
677	83 059	065	07î	078	084	091	097	103	110	116	.6	3.9
678	123	129	136	142	148	155	16î	168	174	180	.7	4.5
679	187	193	200	206	212	219	225	23î	238	244	.8	5.2
680	251	257	263	270	276	283	289	295	302	308	.9	5.8
681	314	321	327	334	340	346	353	359	365	372		
682	378	385	391	397	404	410	416	423	429	435		
683	442	448	455	461	467	474	480	486	493	499		
684	505	512	518	524	531	537	543	550	556	562		
685	569	575	58î	588	594	600	607	613	619	626		
686	632	638	645	65î	657	664	670	676	683	689	6	
687	695	702	708	714	721	727	733	740	746	752	.1	0.6
688	759	765	77î	778	784	790	796	803	809	815	.2	1.2
689	822	828	834	841	847	853	859	866	872	878	.3	1.8
690	885	891	897	904	910	916	922	929	935	94î	.4	2.4
691	948	954	960	966	973	979	985	992	998	*004	.5	3.0
692	84 010	017	023	029	035	042	048	054	061	067	.6	3.6
693	073	079	086	092	098	104	111	117	123	129	.7	4.2
694	136	142	148	154	161	167	173	179	186	192	.8	4.8
695	198	204	211	217	223	229	236	242	248	254	.9	5.4
696	261	267	273	279	286	292	298	304	311	317		
697	323	329	335	342	348	354	360	367	373	379		
698	385	392	398	404	410	416	423	429	435	44î		
699	447	454	460	466	472	479	485	491	497	503		
700	510	516	522	528	534	541	547	553	559	565		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
700	84 510	516	522	528	534	541	547	553	559	565	.1 .2 .3 .4 .5 .6 .7 .8 .9	6 0.6 1.3 1.9 2.6 3.2 3.9 4.5 5.2 5.8
701	572	578	584	590	596	603	609	615	621	627		
702	633	640	646	652	658	664	671	677	683	689		
703	695	701	708	714	720	726	732	739	745	751		
704	757	763	769	776	782	788	794	800	806	813		
705	819	825	831	837	843	849	856	862	868	874		
706	880	886	893	899	905	911	917	923	929	936		
707	942	948	954	960	966	972	979	985	991	997		
708	85 003	009	015	021	028	034	040	046	052	058		
709	064	070	077	083	089	095	101	107	113	119		
710	126	132	138	144	150	156	162	168	174	181	.1 .2 .3 .4 .5 .6 .7 .8 .9	6 0.6 1.3 1.9 2.6 3.2 3.9 4.5 5.2 5.8
711	187	193	199	205	211	217	223	229	236	242		
712	248	254	260	266	272	278	284	290	297	303		
713	309	315	321	327	333	339	345	351	357	363		
714	370	376	382	388	394	400	406	412	418	424		
715	430	436	443	449	455	461	467	473	479	485		
716	491	497	503	509	515	521	527	533	540	546		
717	552	558	564	570	576	582	588	594	600	606		
718	612	618	624	630	636	642	648	655	661	667		
719	673	679	685	691	697	703	709	715	721	727		
720	733	739	745	751	757	763	769	775	781	787	.1 .2 .3 .4 .5 .6 .7 .8 .9	6 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4
721	793	799	805	811	817	823	829	835	841	847		
722	853	859	865	872	878	884	890	896	902	908		
723	914	920	926	932	938	944	950	956	962	968		
724	974	980	986	992	998	*004	*010	*016	*022	*028		
725	86 034	040	046	052	058	063	069	075	081	087		
726	093	099	105	111	117	123	129	135	141	147		
727	153	159	165	171	177	183	189	195	201	207		
728	213	219	225	231	237	243	249	255	261	267		
729	273	278	284	290	296	302	308	314	320	326		
730	332	338	344	350	356	362	368	374	380	386	.1 .2 .3 .4 .5 .6 .7 .8 .9	5 0.5 1.1 1.6 2.2 2.7 3.3 3.8 4.4 4.9
731	391	397	403	409	415	421	427	433	439	445		
732	451	457	463	469	475	481	486	492	498	504		
733	510	516	522	528	534	540	546	552	558	563		
734	569	575	581	587	593	599	605	611	617	623		
735	628	634	640	646	652	658	664	670	676	682		
736	688	693	699	705	711	717	723	729	735	741		
737	746	752	758	764	770	776	782	788	794	800		
738	805	811	817	823	829	835	841	847	852	858		
739	864	870	876	882	888	894	899	905	911	917		
740	923	929	935	941	946	952	958	964	970	976	.1 .2 .3 .4 .5 .6 .7 .8 .9	5 0.5 1.1 1.6 2.2 2.7 3.3 3.8 4.4 4.9
741	982	987	993	999	*005	*011	*017	*023	*028	*034		
742	87 040	046	052	058	064	069	075	081	087	093		
743	099	104	110	116	122	128	134	140	145	151		
744	157	163	169	175	180	186	192	198	204	210		
745	215	221	227	233	239	245	250	256	262	268		
746	274	279	285	291	297	303	309	314	320	326		
747	332	338	343	349	355	361	367	372	378	384		
748	390	396	402	407	413	419	425	431	436	442		
749	448	454	460	465	471	477	483	489	494	500		
750	506	512	517	523	529	535	541	546	552	558		

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
750	87 506	512	517	523	529	535	541	546	552	558		6
751	564	570	575	581	587	593	598	604	610	616		
752	622	627	633	639	645	650	656	662	668	673		
753	679	685	691	697	702	708	714	720	725	731		
754	737	743	748	754	760	766	771	777	783	789		
755	794	800	806	812	817	823	829	835	840	846		
756	852	858	863	869	875	881	886	892	898	904		
757	909	915	921	927	932	938	944	949	955	961		
758	967	972	978	984	990	995	*001	*007	*012	*018		
759	88 024	030	035	041	047	053	058	064	070	075	.1	0.6
760	081	087	093	098	104	110	115	121	127	133	.2	1.2
761	138	144	150	155	161	167	172	178	184	190	.3	1.8
762	195	201	207	212	218	224	229	235	241	247	.4	2.4
763	252	258	264	269	275	281	286	292	298	303	.5	3.0
764	309	315	320	326	332	337	343	349	355	360	.6	3.6
765	366	372	377	383	389	394	400	406	411	417	.7	4.2
766	423	428	434	440	445	451	457	462	468	474	.8	4.8
767	479	485	491	496	502	508	513	519	525	530	.9	5.4
768	536	542	547	553	558	564	570	575	581	587		
769	592	598	604	609	615	621	626	632	638	643		
770	649	654	660	666	671	677	683	688	694	700		
771	705	711	716	722	728	733	739	745	750	756		5
772	761	767	773	778	784	790	795	801	806	812		
773	818	823	829	835	840	846	851	857	863	868		
774	874	879	885	891	896	902	907	913	919	924		
775	930	936	941	947	952	958	964	969	975	980		
776	986	992	997	*003	*008	*014	*019	*025	*031	*036		
777	89 042	047	053	059	064	070	075	081	087	092		
778	098	103	109	114	120	126	131	137	142	148		
779	153	159	165	170	176	181	187	193	198	204		
780	209	215	220	226	231	237	243	248	254	259	.1	0.5
781	265	270	276	282	287	293	298	304	309	315	.2	1.0
782	320	326	332	337	343	348	354	359	365	370	.3	1.5
783	376	381	387	393	398	404	409	415	420	426	.4	2.0
784	431	437	442	448	454	459	465	470	476	481	.5	2.5
785	487	492	498	503	509	514	520	525	531	536	.6	3.0
786	542	548	553	559	564	570	575	581	586	592	.7	3.5
787	597	603	608	614	619	625	630	636	641	647	.8	4.0
788	652	658	663	669	674	680	685	691	696	702	.9	4.5
789	707	713	718	724	729	735	740	746	751	757		
790	762	768	773	779	784	790	795	801	806	812		
791	817	823	828	834	839	845	850	856	861	867		
792	872	878	883	889	894	900	905	911	916	922		
793	927	933	938	943	949	954	960	965	971	976		
794	982	987	993	998	*004	*009	*015	*020	*026	*031		
795	90 036	042	047	053	058	064	069	075	080	086		
796	091	097	102	107	113	118	124	129	135	140		
797	146	151	156	162	167	173	178	184	189	195		
798	200	205	211	216	222	227	233	238	244	249		
799	254	260	265	271	276	282	287	292	298	303		
800	309	314	320	325	330	336	341	347	352	358		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
800	90 309	314	320	325	330	336	341	347	352	358	
801	363	368	374	379	385	390	396	401	406	412	
802	417	423	428	433	439	444	450	455	460	466	
803	471	477	482	488	493	498	504	509	515	520	
804	525	531	536	542	547	552	558	563	569	574	
805	579	585	590	596	601	606	612	617	622	628	
806	633	639	644	649	655	660	666	671	676	682	
807	687	692	698	703	709	714	719	725	730	736	
808	741	746	752	757	762	768	773	778	784	789	
809	795	800	805	811	816	821	827	832	838	843	
810	848	854	859	864	870	875	880	886	891	896	
811	902	907	913	918	923	929	934	939	945	950	
812	955	961	966	971	977	982	987	993	998	*003	.1 5 0.3
813	91 009	014	019	025	030	036	041	046	052	057	.2 1.1 .3 1.6
814	062	068	073	078	084	089	094	100	105	110	
815	116	121	126	131	137	142	147	153	158	163	.4 2.2
816	169	174	179	185	190	195	201	206	211	217	.5 2.7 .6 3.3
817	222	227	233	238	243	249	254	259	264	270	
818	275	280	286	291	296	302	307	312	318	323	.7 3.8
819	328	333	339	344	349	355	360	365	371	376	.8 4.4 .9 4.9
820	381	386	392	397	402	408	413	418	423	429	
821	434	439	445	450	455	461	466	471	476	482	
822	487	492	497	503	508	513	519	524	529	534	
823	540	545	550	556	561	566	571	577	582	587	
824	592	598	603	608	614	619	624	629	635	640	
825	645	650	656	661	666	671	677	682	687	692	
826	698	703	708	714	719	724	729	735	740	745	
827	750	756	761	766	771	777	782	787	792	798	
828	803	808	813	819	824	829	834	839	845	850	
829	855	860	866	871	876	881	887	892	897	902	
830	908	913	918	923	928	934	939	944	949	955	
831	92 960	965	970	976	981	986	991	996	*002	*007	.1 5 0.5
832	012	017	023	028	033	038	043	049	054	059	.2 1.0
833	064	069	075	080	085	090	096	101	106	111	.3 1.5
834	116	122	127	132	137	142	148	153	158	163	
835	168	174	179	184	189	194	200	205	210	215	.4 2.0
836	220	226	231	236	241	246	252	257	262	267	.5 2.5 .6 3.0
837	272	277	283	288	293	298	303	309	314	319	
838	324	329	335	340	345	350	355	360	366	371	.7 3.5
839	376	381	386	391	397	402	407	412	417	423	.8 4.0 .9 4.5
840	428	433	438	443	448	454	459	464	469	474	
841	479	485	490	495	500	505	510	515	521	526	
842	531	536	541	546	552	557	562	567	572	577	
843	583	588	593	598	603	608	613	619	624	629	
844	634	639	644	649	655	660	665	670	675	680	
845	685	691	696	701	706	711	716	721	727	732	
846	737	742	747	752	757	762	768	773	778	783	
847	788	793	798	803	809	814	819	824	829	834	
848	839	844	850	855	860	865	870	875	880	885	
849	891	896	901	906	911	916	921	926	931	937	
850	942	947	952	957	962	967	972	977	982	988	
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
850	92 942	947	952	957	962	967	972	977	982	988	
851	993	998	*003	*008	*013	*018	*023	*028	*034	*039	
852	93 044	049	054	059	064	069	074	079	084	090	
853	095	100	105	110	115	120	125	130	135	140	
854	146	151	156	161	166	171	176	181	186	191	
855	196	201	207	212	217	222	227	232	237	242	
856	247	252	257	262	267	272	278	283	288	293	5
857	298	303	308	313	318	323	328	333	338	343	.1 0.5
858	348	354	359	364	369	374	379	384	389	394	.2 1.1
859	399	404	409	414	419	424	429	434	439	445	.3 1.6
860	450	455	460	465	470	475	480	485	490	495	.4 2.2
861	500	505	510	515	520	525	530	535	540	545	.5 2.7
862	550	556	561	566	571	576	581	586	591	596	.6 3.3
863	601	606	611	616	621	626	631	636	641	646	.7 3.8
864	651	656	661	666	671	676	681	686	691	696	.8 4.4
865	701	706	711	716	721	726	731	736	742	747	.9 4.9
866	752	757	762	767	772	777	782	787	792	797	
867	802	807	812	817	822	827	832	837	842	847	
868	852	857	862	867	872	877	882	887	892	897	
869	902	907	912	917	922	927	932	937	942	947	
870	952	957	962	967	972	977	982	987	992	997	
871	94 002	007	012	017	022	026	031	036	041	046	5
872	051	056	061	066	071	076	081	086	091	096	.1 0.5
873	101	106	111	116	121	126	131	136	141	146	.2 1.0
874	151	156	161	166	171	176	181	186	191	196	.3 1.5
875	201	206	210	215	220	225	230	235	240	245	.4 2.0
876	250	255	260	265	270	275	280	285	290	295	.5 2.5
877	300	305	310	315	320	324	329	334	339	344	.6 3.0
878	349	354	359	364	369	374	379	384	389	394	.7 3.5
879	399	404	409	413	418	423	428	433	438	443	.8 4.0
880	448	453	458	463	468	473	478	483	487	492	.9 4.5
881	497	502	507	512	517	522	527	532	537	542	
882	547	552	556	561	566	571	576	581	586	591	
883	596	601	606	611	615	620	625	630	635	640	
884	645	650	655	660	665	670	674	679	684	689	
885	694	699	704	709	714	719	724	728	733	738	
886	743	748	753	758	763	768	773	777	782	787	4
887	792	797	802	807	812	817	821	826	831	836	.1 0.4
888	841	846	851	856	861	865	870	875	880	885	.2 0.9
889	890	895	900	905	909	914	919	924	929	934	.3 1.3
890	939	944	949	953	958	963	968	973	978	983	.4 1.8
891	988	992	997	*002	*007	*012	*017	*022	*026	031	.5 2.2
892	95 036	041	046	051	056	061	065	070	075	080	.6 2.7
893	085	090	095	099	104	109	114	119	124	129	.7 3.1
894	134	138	143	148	153	158	163	167	172	177	.8 3.6
895	182	187	192	197	201	206	211	216	221	226	.9 4.0
896	231	235	240	245	250	255	260	264	269	274	
897	279	284	289	294	298	303	308	313	318	323	
898	327	332	337	342	347	352	356	361	366	371	
899	376	381	385	390	395	400	405	410	414	419	
900	424	429	434	438	443	448	453	458	463	467	
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.	
900	95 424̂	429	434	438̂	443̂	448̂	453	458	463	467̂		
901	472̂	477̂	482	487	492	496̂	501̂	506	511	516		
902	520̂	525̂	530̂	535	540	544̂	549̂	554̂	559	564		
903	569	573̂	578̂	583	588	593	597̂	602̂	607	612		
904	617	621̂	626̂	631̂	636	641	645̂	650̂	655̂	660		
905	665	669̂	674̂	679̂	684	689	693̂	698̂	703	708		
906	713	717̂	722̂	727	732	737	741̂	746̂	751	756		
907	760̂	765̂	770̂	775	780	784̂	789̂	794	799	804		
908	808̂	813̂	818	823	827̂	832̂	837̂	842	847	851̂		
909	856̂	861	866	870̂	875̂	880̂	885	890	894̂	899̂		
910	904	909	913̂	918̂	923	928	933	937̂	942̂	947		
911	952	956̂	961̂	966	971	975̂	980̂	985	990	994̂		
912	999̂	*004	*009	*014	*018̂	*023̂	*028̂	*033̂	*037̂	*042̂	.1	5 0.5
913	96 047	052	056̂	061̂	066	071	075̂	080̂	085	090	.2	1.0
914	094̂	099̂	104	109	113̂	118̂	123	128	132̂	137̂	.3	1.5
915	142	147	151̂	156̂	161	166	170̂	175̂	180	185	.4	2.0
916	189̂	194̂	199	204	208̂	213	218	222̂	227̂	232	.5	2.5
917	237	241̂	246̂	251	256	260̂	265̂	270	275	279̂	.6	3.0
918	284̂	289	293̂	298̂	303	308	312̂	317̂	322	327	.7	3.5
919	331̂	336̂	341	345̂	350̂	355	360	364̂	369̂	374	.8	4.0
920	379	383̂	388	393	397̂	402̂	407	412	416̂	421	.9	4.5
921	426	430̂	435̂	440	445	449̂	454	459	463̂	468̂		
922	473	478	482̂	487	492	496̂	501̂	506	511	515̂		
923	520	525	529̂	534̂	539	543̂	548̂	553	558	562̂		
924	567	572	576̂	581̂	586	590̂	595̂	600	605	609̂		
925	614	619	623̂	628̂	633	637̂	642̂	647	651̂	656̂		
926	661	666	670̂	675	680	684̂	689	694	698̂	703̂		
927	708	712̂	717̂	722	726̂	731̂	736	741	745̂	750		
928	755	759̂	764	769	773̂	778	783	787̂	792	797		
929	801̂	806	811	815̂	820̂	825	829̂	834̂	839	843̂		
930	848̂	853	857̂	862̂	867	871̂	876̂	881	885̂	890̂		
931	895	899̂	904̂	909	913̂	918̂	923	927̂	932̂	937		
932	941̂	946̂	951	955̂	960	965̂	969̂	974	979	983̂	.1	4 0.4
933	988	993	997̂	*002	*007̂	*011̂	*016̂	*020̂	*025̂	*030̂	.2	0.9
934	97 034̂	039̂	044	048̂	053̂	058	062̂	067	072	076̂	.3	1.3
935	081̂	086̂	090̂	095	099̂	104̂	109	113̂	118̂	123	.4	1.8
936	127̂	132	137	141̂	146	151	155̂	160	164̂	169̂	.5	2.2
937	174	178̂	183	188	192̂	197	202	206̂	211	215̂	.6	2.7
938	220̂	225	229̂	234	239	243̂	248	252̂	257̂	262	.7	3.1̂
939	266̂	271	276	280̂	285	289̂	294̂	299	303̂	308	.8	3.6
940	313	317̂	322	326̂	331̂	336̂	340̂	345	349̂	354̂	.9	4.0
941	359	363̂	368	373	377̂	382	386̂	391̂	396	400̂		
942	405	409̂	414̂	419	423̂	428	432̂	437̂	442	446̂		
943	451	456̂	460̂	465	469̂	474	479	483̂	488	492̂		
944	497	502	506̂	511	515̂	520	525	529̂	534	538̂		
945	543	548	552̂	557	561̂	566	570̂	575̂	580	584̂		
946	589	593̂	598̂	603	607̂	612	616̂	621	626	630̂		
947	635	639̂	644	649	653̂	658	662̂	667	671̂	676̂		
948	681	685̂	690	694̂	699	703̂	708̂	713	717̂	722		
949	726̂	731	736	740̂	745	749̂	754	758̂	763	768		
950	772̂	777	781̂	786	790̂	795	800	804̂	809	813̂		
N.	0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
950	97 772	777	781	786	790	795	800	804	809	813	
951	818	822	827	831	836	841	845	850	854	859	
952	863	868	873	877	882	886	891	895	900	904	
953	909	914	918	923	927	932	936	941	945	950	
954	955	959	964	968	973	977	982	986	991	996	
955	98 000	005	009	014	018	023	027	032	036	041	5
956	046	050	055	059	064	068	073	077	082	086	.1 0.5
957	091	095	100	105	109	114	118	123	127	132	.2 1.0
958	136	141	145	150	154	159	163	168	173	177	.3 1.5
959	182	186	191	195	200	204	209	213	218	222	.4 2.0
960	227	231	236	240	245	249	254	259	263	268	.5 2.5
961	272	277	281	286	290	295	299	304	308	313	.6 3.0
962	317	322	326	331	335	340	344	349	353	358	.7 3.5
963	362	367	371	376	380	385	389	394	398	403	.8 4.0
964	407	412	416	421	425	430	434	439	443	448	.9 4.5
965	452	457	461	466	470	475	479	484	488	493	
966	497	502	506	511	515	520	524	529	533	538	
967	542	547	551	556	560	565	569	574	578	583	
968	587	592	596	601	605	610	614	619	623	628	
969	632	637	641	646	650	655	659	663	668	672	
970	677	681	686	690	695	699	704	708	713	717	4
971	722	726	731	735	740	744	749	753	757	762	.1 0.4
972	766	771	775	780	784	789	793	798	802	807	.2 0.9
973	811	815	820	824	829	833	838	842	847	851	.3 1.3
974	856	860	865	869	873	878	882	887	891	896	.4 1.8
975	900	905	909	914	918	922	927	931	936	940	.5 2.2
976	945	949	954	958	963	967	971	976	980	985	.6 2.7
977	989	994	998	*003	*007	*011	*016	*020	*025	*029	.7 3.1
978	99 034	038	043	047	051	056	060	065	069	074	.8 3.6
979	078	082	087	091	096	100	105	109	113	118	.9 4.0
980	122	127	131	136	140	145	149	153	158	162	
981	167	171	176	180	184	189	193	198	202	206	
982	211	215	220	224	229	233	237	242	246	251	
983	255	260	264	268	273	277	282	286	290	295	
984	299	304	308	312	317	321	326	330	335	339	
985	343	348	352	357	361	365	370	374	379	383	4
986	387	392	396	401	405	409	414	418	423	427	.1 0.4
987	431	436	440	445	449	453	458	462	467	471	.2 0.8
988	475	480	484	489	493	497	502	506	511	515	.3 1.2
989	519	524	528	533	537	541	546	550	554	559	.4 1.6
990	563	568	572	576	581	585	590	594	598	603	.5 2.0
991	607	611	616	620	625	629	633	638	642	647	.6 2.4
992	651	655	660	664	668	673	677	682	686	690	.7 2.8
993	695	699	703	708	712	717	721	725	730	734	.8 3.2
994	738	743	747	751	756	760	765	769	773	778	.9 3.6
995	782	786	791	795	800	804	808	813	817	821	
996	826	830	834	839	843	847	852	856	861	865	
997	869	874	878	882	887	891	895	900	904	908	
998	913	917	922	926	930	935	939	943	948	952	
999	956	961	965	969	974	978	982	987	991	995	
1000	00 000	004	008	013	017	021	026	030	034	039	
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.		
1000	000 000	043	087	130	173	217	260	304	347	390			
01	434	477	521	564	607	651	694	737	781	824			
02	867	911	954	997	*041	*084	*127	*171	*214	*257			
03	001 301	344	387	431	474	517	560	604	647	690			
04	733	777	820	863	906	950	993	*036	*079	*123			
05	002 166	209	252	295	339	382	425	468	511	555			
06	598	641	684	727	770	814	857	900	943	986			
07	003 029	072	115	159	202	245	288	331	374	417			
08	460	503	546	590	633	676	719	762	805	848			
09	891	934	977	*020	*063	*106	*149	*192	*235	*278			
1010	004 321	364	407	450	493	536	579	622	665	708			
11	751	794	837	880	923	966	*009	*051	*094	*137			
12	005 180	223	266	309	352	395	438	481	523	566			
13	609	652	695	738	781	824	866	909	952	995			
14	006 038	081	123	166	209	252	295	337	380	423			
15	466	509	551	594	637	680	722	765	808	851			
16	893	936	979	*022	*064	*107	*150	*193	*235	*278			
17	007 321	363	406	449	491	534	577	620	662	705			
18	748	790	833	875	918	961	*003	*046	*089	131			
19	008 174	217	259	302	344	387	430	472	515	557			
1020	600	642	685	728	770	813	855	898	940	983			
21	009 025	068	111	153	196	238	281	323	366	408			
22	451	493	536	578	621	663	706	748	790	833			
23	875	918	960	*003	*045	*088	*130	*172	*215	*257			
24	010 300	342	385	427	469	512	554	596	639	681			
25	724	766	808	851	893	935	978	*020	*062	*105			
26	011 147	189	232	274	316	359	401	443	486	528			
27	570	612	655	697	739	782	824	866	908	951			
28	993	*035	*077	*120	*162	*204	*246	*288	*331	*373			
29	012 415	457	500	542	584	626	668	710	753	795			
1080	837	879	921	963	*006	*048	*090	*132	174	216			
31	013 258	301	343	385	427	469	511	553	595	637			
32	679	722	764	806	848	890	932	974	*016	*058			
33	014 100	142	184	226	268	310	352	394	436	478			
34	520	562	604	646	688	730	772	814	856	898			
35	940	982	*024	*066	*108	*150	*192	*234	*276	*318			
36	015 360	401	443	485	527	569	611	653	695	737			
37	779	820	862	904	946	988	*030	*072	*113	155			
38	016 197	239	281	323	364	406	448	490	532	573			
39	615	657	699	741	782	824	866	908	950	991			
1040	017 033	075	117	158	200	242	284	325	367	409			
41	450	492	534	576	617	659	701	742	784	826			
42	867	909	951	992	*034	*076	*117	*159	*201	*242			
43	018 284	326	367	409	451	492	534	575	617	659			
44	700	742	783	825	867	908	950	991	*033	*074			
45	019 116	158	199	241	282	324	365	407	448	490			
46	531	573	614	656	697	739	780	822	863	905			
47	946	988	*029	*071	*112	*154	*195	*237	*278	*320			
48	020 361	402	444	485	527	568	610	651	692	734			
49	775	817	858	899	941	982	*024	*065	*106	*148			
1050	021 189	230	272	313	354	396	437	478	520	561			
N.	0	1	2	3	4	5	6	7	8	9	P. P.		

	43	43
.1	4.3	4.3
.2	8.7	8.6
.3	13.0	12.9
.4	17.4	17.2
.5	21.7	21.5
.6	26.1	25.8
.7	30.4	30.1
.8	34.8	34.4
.9	39.1	38.7

	42	42
.1	4.2	4.2
.2	8.5	8.4
.3	12.7	12.6
.4	17.0	16.8
.5	21.2	21.0
.6	25.5	25.2
.7	29.7	29.4
.8	34.0	33.6
.9	38.2	37.8

	41	41
.1	4.1	4.1
.2	8.3	8.2
.3	12.4	12.3
.4	16.6	16.4
.5	20.7	20.5
.6	24.9	24.6
.7	29.0	28.7
.8	33.2	32.8
.9	37.3	36.9

TABLE V.—LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	P. P.
1050	021 189	230	272	313	354	396	437	478	520	561	
51	602	644	685	726	768	809	850	892	933	974	
52	022 015	057	098	139	181	222	263	304	346	387	41
53	428	469	511	552	593	634	676	717	758	799	.1 4.1
54	840	882	923	964	*005	*046	*088	*129	*170	*211	.2 5.3
55	023 252	293	335	376	417	458	499	540	581	623	.3 12.4
56	664	705	746	787	828	869	910	951	993	*034	.4 16.5
57	024 075	116	157	198	239	280	321	362	403	444	.5 20.7
58	485	526	568	609	650	691	732	773	814	855	.6 24.9
59	896	937	978	*019	*060	*101	*142	*183	*224	*265	.7 29.0
1060	025 306	347	388	429	469	510	551	592	633	674	.8 33.2
61	715	756	797	838	879	920	961	*002	*042	*083	.9 37.3
62	026 124	165	206	247	288	329	370	410	451	492	
63	533	574	615	656	696	737	778	819	860	901	41
64	941	982	*023	*064	*105	*145	*186	*227	*268	*309	.1 4.1
65	027 349	390	431	472	512	553	594	635	675	716	.2 8.2
66	757	798	838	879	920	961	*001	*042	*083	*123	.3 12.3
67	028 164	205	246	286	327	368	408	449	490	530	.4 16.4
68	571	612	652	693	734	774	815	856	896	937	.5 20.5
69	977	*018	*059	*099	*140	*181	*221	*262	*302	*343	.6 24.6
1070	029 384	424	465	505	546	586	627	668	708	749	.7 28.7
71	789	830	870	911	951	992	*032	*073	*114	*154	.8 32.8
72	030 195	235	276	316	357	397	438	478	519	559	.9 36.9
73	599	640	680	721	761	802	842	883	923	964	
74	031 004	044	085	125	166	206	247	287	327	368	46
75	408	449	489	529	570	610	651	691	731	772	.1 4.0
76	812	852	893	933	973	*014	*054	*094	*135	*175	.2 8.1
77	032 215	256	296	336	377	417	457	498	538	578	.3 12.1
78	619	659	699	739	780	820	860	900	941	981	.4 16.2
79	033 021	061	102	142	182	222	263	303	343	383	.5 20.3
1080	424	464	504	544	584	625	665	705	745	785	.6 24.3
81	825	866	906	946	986	*026	*066	*107	147	187	.7 28.3
82	034 227	267	307	347	388	428	468	508	548	588	.8 32.4
83	628	668	708	748	789	829	869	909	949	989	.9 36.4
84	035 029	069	109	149	189	229	269	309	349	389	
85	429	470	510	550	590	630	670	710	750	790	40
86	830	870	910	950	990	*029	*069	*109	*149	*189	.1 4.0
87	036 229	269	309	349	389	429	469	509	549	589	.2 8.0
88	629	669	708	748	788	828	868	908	948	988	.3 12.0
89	037 028	068	107	147	187	227	267	307	347	386	.4 16.0
1090	426	466	506	546	586	625	665	705	745	785	.5 20.0
91	825	864	904	944	984	*023	*063	*103	143	183	.6 24.0
92	038 222	262	302	342	381	421	461	501	540	580	.7 28.0
93	620	660	699	739	779	819	858	898	938	977	.8 32.0
94	039 017	057	096	136	176	216	255	295	335	374	.9 36.0
95	414	454	493	533	572	612	652	691	731	771	
96	810	850	890	929	969	*008	*048	*088	*127	*167	39
97	040 206	246	286	325	365	404	444	483	523	563	.1 3.9
98	602	642	681	721	760	800	839	879	918	958	.2 7.9
99	997	*037	*076	*116	*155	*195	*234	*274	*313	*353	.3 11.9
1100	041 392	432	471	511	550	590	629	669	708	748	.4 15.9
N.	0	1	2	3	4	5	6	7	8	9	P. P.

TABLE VI.—LOGARITHMIC SINES AND TANGENTS OF SMALL ANGLES.

log sin ϕ = log ϕ'' + S. log tan ϕ = log ϕ'' + T.		O°		log ϕ'' = log sin ϕ + S'. log ϕ'' = log tan ϕ + T'.			
"	'	S	T	Log. Sin.	S'	T'	Log. Tan.
0	0	4.685 57	57	— ∞	5.314 42	42	— ∞
60	1	57	57	6.46 372	42	42	6.46 372
120	2	57	57	.76 475	42	42	.76 475
180	3	57	57	.94 084	42	42	.94 084
240	4	57	57	7.06 578	42	42	7.06 578
300	5	4.685 57	57	7.16 269	5.314 42	42	7.16 269
360	6	57	57	.24 187	42	42	.24 188
420	7	57	57	.30 882	42	42	.30 882
480	8	57	57	.36 681	42	42	.36 681
540	9	57	57	.41 797	42	42	.41 797
600	10	4.685 57	57	7.46 372	5.314 42	42	7.46 372
660	11	57	57	.50 512	42	42	.50 512
720	12	57	57	.54 296	42	42	.54 291
780	13	57	57	.57 767	42	42	.57 767
840	14	57	57	.60 985	42	42	.60 985
900	15	4.685 57	58	7.63 981	5.314 42	42	7.63 982
960	16	57	58	.66 784	42	42	.66 785
1020	17	57	58	.69 417	42	42	.69 418
1080	18	57	58	.71 899	42	42	.71 906
1140	19	57	58	.74 248	42	42	.74 248
1200	20	4.685 57	58	7.76 475	5.314 43	42	7.76 476
1260	21	57	58	.78 594	43	42	.78 595
1320	22	57	58	.80 614	43	42	.80 615
1380	23	57	58	.82 545	43	42	.82 546
1440	24	57	58	.84 393	43	42	.84 394
1500	25	4.685 57	58	7.86 166	5.314 43	41	7.86 167
1560	26	57	58	.87 869	43	41	.87 871
1620	27	57	58	.89 508	43	41	.89 510
1680	28	57	58	.91 088	43	41	.91 089
1740	29	57	58	.92 612	43	41	.92 613
1800	30	4.685 57	58	7.94 084	5.314 43	41	7.94 086
1860	31	57	58	.95 508	43	41	.95 510
1920	32	57	58	.96 887	43	41	.96 889
1980	33	57	59	.98 223	43	41	.98 225
2040	34	57	59	.99 520	43	41	.99 522
2100	35	4.685 56	59	8.00 778	5.314 43	41	8.00 781
2160	36	56	59	.02 002	43	41	.02 004
2220	37	56	59	.03 192	43	41	.03 194
2280	38	56	59	.04 350	43	40	.04 352
2340	39	56	59	.05 478	43	40	.05 481
2400	40	4.685 56	59	8.06 577	5.314 43	40	8.06 580
2460	41	56	59	.07 650	43	40	.07 653
2520	42	56	59	.08 696	43	40	.08 699
2580	43	56	60	.09 718	43	40	.09 721
2640	44	56	60	.10 716	43	40	.10 720
2700	45	4.685 56	60	8.11 692	5.314 44	40	8.11 696
2760	46	56	60	.12 647	44	40	.12 651
2820	47	56	60	.13 581	44	40	.13 585
2880	48	56	60	.14 495	44	39	.14 499
2940	49	56	60	.15 390	44	39	.15 395
3000	50	4.685 56	60	8.16 268	5.314 44	39	8.16 272
3060	51	56	60	.17 128	44	39	.17 133
3120	52	56	61	.17 971	44	39	.17 976
3180	53	56	61	.18 798	44	39	.18 803
3240	54	55	61	.19 610	44	39	.19 615
3300	55	4.685 55	61	8.20 407	5.314 44	39	8.20 412
3360	56	55	61	.21 189	44	38	.21 195
3420	57	55	61	.21 958	44	38	.21 964
3480	58	55	61	.22 713	44	38	.22 719
3540	59	55	62	.23 455	44	38	.23 462

TABLE VI.—LOGARITHMIC SINES AND TANGENTS OF SMALL ANGLES.

log sin ϕ = log ϕ'' + S. log tan ϕ = log ϕ'' + T.				1°	log ϕ' = log sin ϕ + S'. log ϕ' = log tan ϕ + T'.		
''	'	S	T	Log. Sin.	S'	T'	Log. Tan.
3600	0	4.685 55	62	8.24 185	5.314 44	38	8.24 192
3660	1	55	62	.24 903	45	38	.24 910
3720	2	55	62	.25 609	45	38	.25 616
3780	3	55	62	.26 304	45	37	.26 311
3840	4	55	62	.26 988	45	37	.26 995
3900	5	4.685 55	62	8.27 661	5.314 45	37	8.27 669
3960	6	55	63	.28 324	45	37	.28 332
4020	7	54	63	.28 977	45	37	.28 985
4080	8	54	63	.29 626	45	37	.29 629
4140	9	54	63	.30 254	45	36	.30 263
4200	10	4.685 54	63	8.30 879	5.314 45	36	8.30 888
4260	11	54	63	.31 495	45	36	.31 504
4320	12	54	64	.32 102	45	36	.32 112
4380	13	54	64	.32 701	46	36	.32 711
4440	14	54	64	.33 292	46	36	.33 302
4500	15	4.685 54	64	8.33 875	5.314 46	35	8.33 885
4560	16	54	64	.34 456	46	35	.34 461
4620	17	54	65	.35 018	46	35	.35 029
4680	18	54	65	.35 578	46	35	.35 589
4740	19	53	65	.36 131	46	35	.36 143
4800	20	4.685 53	65	8.36 677	5.314 46	34	8.36 689
4860	21	53	65	.37 217	46	34	.37 229
4920	22	53	65	.37 750	46	34	.37 762
4980	23	53	66	.38 276	46	34	.38 289
5040	24	53	66	.38 796	47	34	.38 809
5100	25	4.685 53	66	8.39 310	5.314 47	33	8.39 323
5160	26	53	66	.39 818	47	33	.39 831
5220	27	53	67	.40 320	47	33	.40 334
5280	28	52	67	.40 816	47	33	.40 830
5340	29	52	67	.41 307	47	33	.41 321
5400	30	4.685 52	67	8.41 792	5.314 47	32	8.41 807
5460	31	52	67	.42 271	47	32	.42 287
5520	32	52	68	.42 746	47	32	.42 762
5580	33	52	68	.43 215	48	32	.43 231
5640	34	52	68	.43 680	48	31	.43 696
5700	35	4.685 52	68	8.44 139	5.314 48	31	8.44 156
5760	36	52	69	.44 594	48	31	.44 611
5820	37	51	69	.45 044	48	31	.45 061
5880	38	51	69	.45 489	48	30	.45 507
5940	39	51	69	.45 930	48	30	.45 948
6000	40	4.685 51	69	8.46 366	5.314 48	30	8.46 385
6060	41	51	70	.46 798	49	30	.46 817
6120	42	51	70	.47 226	49	30	.47 245
6180	43	51	70	.47 650	49	29	.47 669
6240	44	51	70	.48 069	49	29	.48 089
6300	45	4.685 50	71	8.48 485	5.314 49	29	8.48 505
6360	46	50	71	.48 896	49	28	.48 917
6420	47	50	71	.49 304	49	28	.49 325
6480	48	50	72	.49 708	49	28	.49 729
6540	49	50	72	.50 108	50	28	.50 130
6600	50	4.685 50	72	8.50 504	5.314 50	27	8.50 526
6660	51	50	72	.50 897	50	27	.50 920
6720	52	50	73	.51 286	50	27	.51 310
6780	53	49	73	.51 672	50	27	.51 696
6840	54	49	73	.52 055	50	26	.52 079
6900	55	4.685 49	73	8.52 434	5.314 50	26	8.52 458
6960	56	49	74	.52 810	51	26	.52 835
7020	57	49	74	.53 183	51	25	.53 208
7080	58	49	74	.53 552	51	25	.53 578
7140	59	49	75	.53 918	51	25	.53 944

TABLE VI.—LOGARITHMIC SINES AND TANGENTS OF SMALL ANGLES.

log sin $\phi = \log \phi'' + S$ log tan $\phi = \log \phi'' + T$		2°						log $\phi'' = \log \sin \phi + S'$ log $\phi'' = \log \tan \phi + T'$	
"	'	S	T	Log. Sin.	S'	T'	Log. Tan.		
7200	0	4.685 48	75	8.54 282	5.314 51	25	8.54 308		
7260	1	48	75	.54 642	51	24	.54 669		
7320	2	48	75	.54 999	51	24	.55 027		
7380	3	48	76	.55 354	52	24	.55 381		
7440	4	48	76	.55 705	52	23	.55 733		
7500	5	4.685 48	76	8.56 054	5.314 52	23	8.56 083		
7560	6	48	77	.56 400	52	23	.56 429		
7620	7	47	77	.56 743	52	22	.56 772		
7680	8	47	77	.57 083	52	22	.57 113		
7740	9	47	78	.57 421	52	22	.57 452		
7800	10	4.685 47	78	8.57 756	5.314 53	22	8.57 787		
7860	11	47	78	.58 089	53	21	.58 121		
7920	12	47	79	.58 419	53	21	.58 451		
7980	13	46	79	.58 747	53	21	.58 779		
8040	14	46	79	.59 072	53	20	.59 105		
8100	15	4.685 46	80	8.59 395	5.314 53	20	8.59 428		
8160	16	46	80	.59 715	54	20	.59 749		
8220	17	46	80	.60 033	54	19	.60 067		
8280	18	46	81	.60 349	54	19	.60 384		
8340	19	45	81	.60 662	54	19	.60 698		
8400	20	4.685 45	81	8.60 973	5.314 54	18	8.61 009		
8460	21	45	82	.61 282	54	18	.61 319		
8520	22	45	82	.61 589	55	18	.61 626		
8580	23	45	82	.61 893	55	17	.61 931		
8640	24	45	83	.62 196	55	17	.62 234		
8700	25	4.685 44	83	8.62 496	5.314 55	16	8.62 535		
8760	26	44	83	.62 795	55	16	.62 834		
8820	27	44	84	.63 091	55	16	.63 131		
8880	28	44	84	.63 385	56	15	.63 425		
8940	29	44	84	.63 677	56	15	.63 718		
9000	30	4.685 43	85	8.63 968	5.314 56	15	8.64 009		
9060	31	43	85	.64 256	56	14	.64 298		
9120	32	43	86	.64 543	56	14	.64 585		
9180	33	43	86	.64 827	57	14	.64 870		
9240	34	43	86	.65 110	57	13	.65 153		
9300	35	4.685 43	87	8.65 391	5.314 57	13	8.65 435		
9360	36	42	87	.65 670	57	12	.65 715		
9420	37	42	87	.65 947	57	12	.65 993		
9480	38	42	88	.66 223	58	12	.66 269		
9540	39	42	88	.66 497	58	11	.66 543		
9600	40	4.685 42	89	8.66 769	5.314 58	11	8.66 816		
9660	41	41	89	.67 039	58	10	.67 087		
9720	42	41	89	.67 308	58	10	.67 356		
9780	43	41	90	.67 575	59	10	.67 624		
9840	44	41	90	.67 840	59	09	.67 890		
9900	45	4.685 41	91	8.68 104	5.314 59	09	8.68 154		
9960	46	40	91	.68 366	59	08	.68 417		
10020	47	40	91	.68 627	59	08	.68 678		
10080	48	40	92	.68 886	60	08	.68 938		
10140	49	40	92	.69 144	60	07	.69 196		
10200	50	4.685 40	93	8.69 400	5.314 60	07	8.69 453		
10260	51	39	93	.69 654	60	06	.69 708		
10320	52	39	93	.69 907	60	06	.69 961		
10380	53	39	94	.70 159	61	06	.70 214		
10440	54	39	94	.70 409	61	05	.70 464		
10500	55	4.685 38	95	8.70 657	5.314 61	05	8.70 714		
10560	56	38	95	.70 905	61	04	.70 962		
10620	57	38	96	.71 150	61	04	.71 208		
10680	58	38	96	.71 395	62	03	.71 453		
10740	59	38	97	.71 638	62	03	.71 697		

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
0°

'	Log. Sin.	D	Log. Tan.	Com. D.	Log. Cot.	Log. Cos.	
0	— ∞		— ∞		+ ∞	0.00 000	60
1	6.46 372	30103	6.46 372	30103	3.53 627	0.00 000	59
2	6.76 475	17609	6.76 475	17609	3.23 524	0.00 000	58
3	6.94 084	12494	6.94 084	12494	3.05 915	0.00 000	57
4	7.06 578	9691	7.06 578	9691	2.93 421	0.00 000	56
5	7.16 269	7918	7.16 269	7918	2.83 736	0.00 000	55
6	7.24 187	6695	7.24 188	6694	2.75 812	0.00 000	54
7	7.30 882	5799	7.30 882	5799	2.69 117	0.00 000	53
8	7.36 681	5113	7.36 681	5113	2.63 318	0.00 000	52
9	7.41 797	4573	7.41 797	4573	2.58 203	0.00 000	51
10	7.46 372	4139	7.46 372	4139	2.53 627	0.00 000	50
11	7.50 512	3778	7.50 512	3779	2.49 488	0.00 000	49
12	7.54 296	3476	7.54 291	3476	2.45 709	9.99 999	48
13	7.57 767	3218	7.57 767	3218	2.42 233	9.99 999	47
14	7.60 985	2996	7.60 985	2996	2.39 014	9.99 999	46
15	7.63 981	2803	7.63 982	2803	2.36 018	9.99 999	45
16	7.66 784	2633	7.66 785	2633	2.33 215	9.99 999	44
17	7.69 417	2482	7.69 418	2482	2.30 582	9.99 999	43
18	7.71 899	2348	7.71 900	2348	2.28 099	9.99 999	42
19	7.74 248	2227	7.74 248	2227	2.25 751	9.99 999	41
20	7.76 475	2119	7.76 476	2119	2.23 524	9.99 999	40
21	7.78 594	2020	7.78 595	2020	2.21 405	9.99 999	39
22	7.80 614	1936	7.80 615	1936	2.19 384	9.99 999	38
23	7.82 545	1848	7.82 546	1848	2.17 454	9.99 999	37
24	7.84 393	1772	7.84 394	1773	2.15 605	9.99 999	36
25	7.86 166	1703	7.86 167	1703	2.13 832	9.99 999	35
26	7.87 869	1639	7.87 871	1639	2.12 129	9.99 999	34
27	7.89 508	1579	7.89 510	1579	2.10 490	9.99 998	33
28	7.91 088	1524	7.91 089	1524	2.08 916	9.99 998	32
29	7.92 612	1472	7.92 613	1472	2.07 386	9.99 998	31
30	7.94 084	1424	7.94 086	1424	2.05 914	9.99 998	30
31	7.95 508	1379	7.95 510	1379	2.04 490	9.99 998	29
32	7.96 887	1336	7.96 889	1336	2.03 111	9.99 998	28
33	7.98 223	1296	7.98 225	1296	2.01 774	9.99 998	27
34	7.99 520	1258	7.99 522	1259	2.00 478	9.99 998	26
35	8.00 778	1223	8.00 781	1223	1.99 219	9.99 997	25
36	8.02 002	1190	8.02 004	1190	1.97 995	9.99 997	24
37	8.03 192	1158	8.03 194	1158	1.96 805	9.99 997	23
38	8.04 350	1128	8.04 352	1128	1.95 647	9.99 997	22
39	8.05 478	1099	8.05 481	1099	1.94 519	9.99 997	21
40	8.06 577	1072	8.06 580	1072	1.93 419	9.99 997	20
41	8.07 650	1046	8.07 653	1046	1.92 347	9.99 997	19
42	8.08 696	1022	8.08 699	1022	1.91 306	9.99 997	18
43	8.09 718	998	8.09 721	999	1.90 278	9.99 996	17
44	8.10 716	976	8.10 720	976	1.89 279	9.99 996	16
45	8.11 692	954	8.11 696	954	1.88 303	9.99 996	15
46	8.12 647	934	8.12 651	934	1.87 349	9.99 996	14
47	8.13 581	914	8.13 585	914	1.86 415	9.99 996	13
48	8.14 495	895	8.14 499	895	1.85 500	9.99 996	12
49	8.15 396	877	8.15 395	877	1.84 605	9.99 995	11
50	8.16 268	860	8.16 272	866	1.83 727	9.99 995	10
51	8.17 128	843	8.17 133	843	1.82 867	9.99 995	9
52	8.17 971	827	8.17 976	827	1.82 023	9.99 995	8
53	8.18 798	811	8.18 803	812	1.81 196	9.99 995	7
54	8.19 610	797	8.19 615	797	1.80 384	9.99 994	6
55	8.20 407	782	8.20 412	783	1.79 587	9.99 994	5
56	8.21 189	768	8.21 195	768	1.78 804	9.99 994	4
57	8.21 958	753	8.21 964	753	1.78 036	9.99 994	3
58	8.22 713	742	8.22 719	742	1.77 286	9.99 994	2
59	8.23 455	730	8.23 462	730	1.76 538	9.99 993	1
60	8.24 185		8.24 192		1.75 808	9.99 993	0
	Log. Cos.	D	Log. Cot.	Com. D.	Log. Tan.	Log. Sin.	

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
1°

'	Log. Sin.	D	Log. Tan.	Com. D.	Log. Cot.	Log. Cos.	
0	8.24 183	718	8.24 192	718	1.75 808	9.99 993	60
1	8.24 903	706	8.24 910	706	1.75 090	9.99 993	59
2	8.25 609	694	8.25 616	695	1.74 383	9.99 993	58
3	8.26 304	684	8.26 311	684	1.73 688	9.99 992	57
4	8.26 988	673	8.26 995	673	1.73 004	9.99 992	56
5	8.27 661	663	8.27 669	663	1.72 331	9.99 992	55
6	8.28 324	653	8.28 332	653	1.71 667	9.99 992	54
7	8.28 977	643	8.28 985	643	1.71 014	9.99 992	53
8	8.29 620	634	8.29 629	634	1.70 371	9.99 991	52
9	8.30 254	625	8.30 263	625	1.69 736	9.99 991	51
10	8.30 879	616	8.30 888	616	1.69 111	9.99 991	50
11	8.31 495	607	8.31 504	607	1.68 495	9.99 990	49
12	8.32 102	599	8.32 112	599	1.67 888	9.99 990	48
13	8.32 701	591	8.32 711	591	1.67 288	9.99 990	47
14	8.33 292	583	8.33 302	583	1.66 697	9.99 990	46
15	8.33 875	575	8.33 885	575	1.66 114	9.99 989	45
16	8.34 450	567	8.34 461	568	1.65 539	9.99 989	44
17	8.35 018	560	8.35 029	560	1.64 971	9.99 989	43
18	8.35 578	553	8.35 589	553	1.64 410	9.99 989	42
19	8.36 131	546	8.36 143	546	1.63 857	9.99 988	41
20	8.36 677	539	8.36 689	539	1.63 310	9.99 988	40
21	8.37 217	533	8.37 229	533	1.62 771	9.99 988	39
22	8.37 750	526	8.37 762	527	1.62 238	9.99 987	38
23	8.38 276	520	8.38 289	520	1.61 711	9.99 987	37
24	8.38 796	514	8.38 809	514	1.61 191	9.99 987	36
25	8.39 310	508	8.39 323	508	1.60 676	9.99 986	35
26	8.39 818	502	8.39 831	502	1.60 168	9.99 986	34
27	8.40 320	496	8.40 334	496	1.59 666	9.99 986	33
28	8.40 816	491	8.40 830	491	1.59 169	9.99 986	32
29	8.41 307	485	8.41 321	485	1.58 678	9.99 985	31
30	8.41 792	479	8.41 807	480	1.58 193	9.99 985	30
31	8.42 271	474	8.42 287	475	1.57 713	9.99 985	29
32	8.42 746	469	8.42 762	469	1.57 238	9.99 984	28
33	8.43 215	464	8.43 231	464	1.56 768	9.99 984	27
34	8.43 680	459	8.43 696	460	1.56 304	9.99 984	26
35	8.44 139	454	8.44 156	455	1.55 844	9.99 983	25
36	8.44 594	450	8.44 611	450	1.55 389	9.99 983	24
37	8.45 044	445	8.45 061	445	1.54 938	9.99 982	23
38	8.45 489	440	8.45 507	441	1.54 493	9.99 982	22
39	8.45 930	436	8.45 948	437	1.54 052	9.99 982	21
40	8.46 366	432	8.46 385	432	1.53 615	9.99 981	20
41	8.46 798	428	8.46 817	428	1.53 183	9.99 981	19
42	8.47 226	423	8.47 245	424	1.52 754	9.99 981	18
43	8.47 650	419	8.47 669	419	1.52 330	9.99 980	17
44	8.48 069	415	8.48 089	416	1.51 911	9.99 980	16
45	8.48 485	411	8.48 505	412	1.51 495	9.99 979	15
46	8.48 896	407	8.48 917	408	1.51 083	9.99 979	14
47	8.49 304	404	8.49 325	404	1.50 675	9.99 979	13
48	8.49 708	400	8.49 729	400	1.50 270	9.99 978	12
49	8.50 108	396	8.50 130	396	1.49 870	9.99 978	11
50	8.50 504	393	8.50 526	393	1.49 473	9.99 978	10
51	8.50 897	389	8.50 920	390	1.49 080	9.99 977	9
52	8.51 286	386	8.51 310	386	1.48 690	9.99 977	8
53	8.51 672	382	8.51 696	383	1.48 304	9.99 976	7
54	8.52 055	379	8.52 079	379	1.47 921	9.99 976	6
55	8.52 434	375	8.52 458	376	1.47 541	9.99 975	5
56	8.52 810	373	8.52 835	373	1.47 165	9.99 975	4
57	8.53 183	369	8.53 208	370	1.46 792	9.99 975	3
58	8.53 552	366	8.53 578	366	1.46 422	9.99 974	2
59	8.53 918	363	8.53 944	364	1.46 055	9.99 974	1
60	8.54 282		8.54 308		1.45 691	9.99 973	0
	Log. Cos.	D	Log. Cot.	Com. D.	Log. Tan.	Log. Sin.	'

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

2°

'	Log. Sin.	D	Log. Tan.	Com. D.	Log. Cot.	Log. Cos.	
0	8.54 282		8.54 308		1.45 691	9.99 973	60
1	8.54 642	360	8.54 669	366	1.45 331	9.99 973	59
2	8.54 999	357	8.55 027	358	1.44 973	9.99 972	58
3	8.55 354	354	8.55 381	354	1.44 618	9.99 972	57
4	8.55 705	351	8.55 733	352	1.44 266	9.99 971	56
5	8.56 054	348	8.56 083	346	1.43 917	9.99 971	55
6	8.56 400	346	8.56 429	346	1.43 571	9.99 971	54
7	8.56 743	343	8.56 772	343	1.43 227	9.99 970	53
8	8.57 083	340	8.57 113	341	1.42 886	9.99 970	52
9	8.57 421	338	8.57 452	338	1.42 548	9.99 969	51
10	8.57 756	335	8.57 787	333	1.42 212	9.99 969	50
11	8.58 089	332	8.58 121	333	1.41 879	9.99 968	49
12	8.58 419	330	8.58 451	330	1.41 548	9.99 968	48
13	8.58 747	327	8.58 779	328	1.41 220	9.99 967	47
14	8.59 072	325	8.59 105	323	1.40 895	9.99 967	46
15	8.59 395	323	8.59 428	323	1.40 571	9.99 966	45
16	8.59 715	320	8.59 749	326	1.40 251	9.99 966	44
17	8.60 033	318	8.60 067	318	1.39 932	9.99 965	43
18	8.60 349	316	8.60 384	316	1.39 616	9.99 965	42
19	8.60 662	313	8.60 698	314	1.39 302	9.99 964	41
20	8.60 973	311	8.61 009	311	1.38 990	9.99 964	40
21	8.61 282	309	8.61 319	309	1.38 681	9.99 963	39
22	8.61 589	306	8.61 626	307	1.38 374	9.99 963	38
23	8.61 893	304	8.61 931	303	1.38 068	9.99 962	37
24	8.62 196	302	8.62 234	303	1.37 765	9.99 962	36
25	8.62 496	300	8.62 535	303	1.37 465	9.99 961	35
26	8.62 795	298	8.62 834	299	1.37 166	9.99 961	34
27	8.63 091	296	8.63 131	297	1.36 869	9.99 960	33
28	8.63 385	294	8.63 425	294	1.36 574	9.99 959	32
29	8.63 677	292	8.63 718	293	1.36 281	9.99 959	31
30	8.63 968	290	8.64 009	291	1.35 990	9.99 958	30
31	8.64 256	288	8.64 298	288	1.35 702	9.99 958	29
32	8.64 543	286	8.64 585	287	1.35 414	9.99 957	28
33	8.64 827	284	8.64 870	285	1.35 129	9.99 957	27
34	8.65 110	282	8.65 153	283	1.34 846	9.99 956	26
35	8.65 391	281	8.65 435	281	1.34 565	9.99 956	25
36	8.65 670	279	8.65 715	280	1.34 285	9.99 955	24
37	8.65 947	277	8.65 993	278	1.34 007	9.99 954	23
38	8.66 223	275	8.66 269	276	1.33 731	9.99 954	22
39	8.66 497	274	8.66 543	274	1.33 456	9.99 953	21
40	8.66 769	272	8.66 816	272	1.33 184	9.99 953	20
41	8.67 039	270	8.67 087	271	1.32 913	9.99 952	19
42	8.67 308	268	8.67 356	269	1.32 643	9.99 952	18
43	8.67 575	267	8.67 624	267	1.32 376	9.99 951	17
44	8.67 840	265	8.67 890	266	1.32 110	9.99 950	16
45	8.68 104	264	8.68 154	264	1.31 845	9.99 950	15
46	8.68 366	262	8.68 417	262	1.31 583	9.99 949	14
47	8.68 627	260	8.68 678	261	1.31 321	9.99 948	13
48	8.68 886	259	8.68 938	259	1.31 062	9.99 948	12
49	8.69 144	257	8.69 196	258	1.30 803	9.99 947	11
50	8.69 400	256	8.69 453	256	1.30 547	9.99 947	10
51	8.69 654	254	8.69 708	255	1.30 292	9.99 946	9
52	8.69 907	253	8.69 961	253	1.30 038	9.99 945	8
53	8.70 159	251	8.70 214	252	1.29 786	9.99 945	7
54	8.70 409	250	8.70 464	250	1.29 535	9.99 944	6
55	8.70 657	248	8.70 714	249	1.29 286	9.99 943	5
56	8.70 905	247	8.70 962	248	1.29 038	9.99 943	4
57	8.71 150	245	8.71 208	246	1.28 791	9.99 942	3
58	8.71 395	244	8.71 453	245	1.28 546	9.99 942	2
59	8.71 638	243	8.71 697	243	1.28 303	9.99 941	1
60	8.71 880	241	8.71 939	242	1.28 060	9.99 940	0
	Log. Cos.	D	Log. Cot.	Com. D.	Log. Tan.	Log. Sin.	'

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

3°

°	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.			
								330	320	310	300
0	8.71 880	248	8.71 936	241	1.28 060	9.99 940	60				
1	8.72 128	239	8.72 180	242	1.27 816	9.99 940	59				
2	8.72 356	237	8.72 420	240	1.27 579	9.99 939	58				
3	8.72 577	236	8.72 659	238	1.27 341	9.99 938	57				
4	8.72 793	235	8.72 896	237	1.27 104	9.99 938	56				
5	8.73 009	233	8.73 131	235	1.26 868	9.99 937	55				
6	8.73 222	233	8.73 366	235	1.26 633	9.99 936	54				
7	8.73 435	231	8.73 599	233	1.26 400	9.99 935	53				
8	8.73 646	231	8.73 831	232	1.26 168	9.99 935	52				
9	8.73 857	230	8.74 062	231	1.25 937	9.99 934	51				
10	8.74 226	229	8.74 292	229	1.25 708	9.99 933	50				
11	8.74 453	227	8.74 528	228	1.25 479	9.99 933	49				
12	8.74 680	226	8.74 748	227	1.25 252	9.99 932	48				
13	8.74 905	225	8.74 974	226	1.25 026	9.99 931	47				
14	8.75 129	224	8.75 199	225	1.24 801	9.99 931	46				
15	8.75 353	223	8.75 422	223	1.24 577	9.99 930	45				
16	8.75 574	222	8.75 645	223	1.24 354	9.99 929	44				
17	8.75 795	221	8.75 867	222	1.24 133	9.99 928	43				
18	8.76 015	219	8.76 087	220	1.23 913	9.99 928	42				
19	8.76 233	218	8.76 306	219	1.23 693	9.99 927	41				
20	8.76 451	217	8.76 524	218	1.23 475	9.99 926	40				
21	8.76 669	216	8.76 741	217	1.23 258	9.99 925	39				
22	8.76 883	215	8.76 958	216	1.23 042	9.99 925	38				
23	8.77 097	214	8.77 172	214	1.22 827	9.99 924	37				
24	8.77 310	213	8.77 386	214	1.22 613	9.99 923	36				
25	8.77 522	212	8.77 599	213	1.22 400	9.99 922	35				
26	8.77 733	211	8.77 811	212	1.22 188	9.99 922	34				
27	8.77 943	210	8.78 022	210	1.21 978	9.99 921	33				
28	8.78 152	209	8.78 232	210	1.21 768	9.99 920	32				
29	8.78 363	208	8.78 441	209	1.21 559	9.99 919	31				
30	8.78 567	207	8.78 648	207	1.21 351	9.99 919	30				
31	8.78 773	206	8.78 855	206	1.21 144	9.99 918	29				
32	8.78 978	205	8.79 061	206	1.20 938	9.99 917	28				
33	8.79 183	204	8.79 266	204	1.20 734	9.99 916	27				
34	8.79 386	203	8.79 470	204	1.20 530	9.99 916	26				
35	8.79 588	202	8.79 673	203	1.20 327	9.99 915	25				
36	8.79 789	201	8.79 875	202	1.20 125	9.99 914	24				
37	8.79 989	200	8.80 076	200	1.19 923	9.99 913	23				
38	8.80 189	199	8.80 276	200	1.19 723	9.99 912	22				
39	8.80 387	198	8.80 476	199	1.19 524	9.99 912	21				
40	8.80 585	197	8.80 674	198	1.19 326	9.99 911	20				
41	8.80 782	197	8.80 871	197	1.19 128	9.99 910	19				
42	8.80 977	195	8.81 068	197	1.18 931	9.99 909	18				
43	8.81 172	195	8.81 264	198	1.18 736	9.99 908	17				
44	8.81 366	194	8.81 459	195	1.18 541	9.99 907	16				
45	8.81 560	193	8.81 653	194	1.18 347	9.99 907	15				
46	8.81 752	192	8.81 846	193	1.18 154	9.99 906	14				
47	8.81 943	191	8.82 038	192	1.17 961	9.99 905	13				
48	8.82 134	191	8.82 230	192	1.17 770	9.99 904	12				
49	8.82 324	189	8.82 426	190	1.17 579	9.99 903	11				
50	8.82 513	188	8.82 616	188	1.17 389	9.99 902	10				
51	8.82 701	187	8.82 799	188	1.17 201	9.99 902	9				
52	8.82 888	186	8.82 987	187	1.17 013	9.99 901	8				
53	8.83 075	185	8.83 175	186	1.16 825	9.99 900	7				
54	8.83 260	183	8.83 361	185	1.16 638	9.99 899	6				
55	8.83 445	183	8.83 547	183	1.16 453	9.99 898	5				
56	8.83 629	181	8.83 732	184	1.16 268	9.99 897	4				
57	8.83 813	180	8.83 916	183	1.16 083	9.99 896	3				
58	8.83 995	179	8.84 100	182	1.15 900	9.99 896	2				
59	8.84 177	178	8.84 282	181	1.15 717	9.99 895	1				
60	8.84 358	177	8.84 464	180	1.15 535	9.99 894	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.		P. P.			

86°

S. Sin.		d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	P. P.				
34 358	180		8.84 464	181	1.15 535	9.99 894	60				
34 538	180		8.84 645	186	1.15 354	9.99 893	59				
34 718	178		8.84 826	179	1.15 174	9.99 892	58				
34 897	178		8.85 005	179	1.14 994	9.99 891	57				
35 075	177		8.85 184	178	1.14 815	9.99 890	56				
85 252	176		8.85 363	177	1.14 637	9.99 889	55				
85 429	176		8.85 540	176	1.14 459	9.99 888	54				
85 605	175		8.85 717	176	1.14 283	9.99 888	53				
85 780	174		8.85 893	175	1.14 107	9.99 887	52				
85 954	174		8.86 068	175	1.13 931	9.99 886	51				
86 128	173		8.86 243	174	1.13 756	9.99 885	50				
86 301	172		8.86 417	173	1.13 582	9.99 884	49				
86 474	171		8.86 590	172	1.13 409	9.99 883	48				
86 645	171		8.86 763	172	1.13 237	9.99 882	47				
86 816	170		8.86 935	171	1.13 065	9.99 881	46				
86 987	169		8.87 106	170	1.12 893	9.99 880	45				
87 156	169		8.87 277	170	1.12 723	9.99 879	44				
87 325	168		8.87 447	169	1.12 553	9.99 878	43				
87 494	167		8.87 616	169	1.12 384	9.99 877	42				
87 661	167		8.87 785	168	1.12 215	9.99 876	41				
87 828	166		8.87 953	167	1.12 047	9.99 875	40				
87 995	165		8.88 120	167	1.11 880	9.99 874	39				
88 160	165		8.88 287	166	1.11 713	9.99 874	38				
88 326	164		8.88 453	165	1.11 547	9.99 873	37				
88 490	163		8.88 618	164	1.11 381	9.99 872	36				
88 654	163		8.88 783	164	1.11 216	9.99 871	35				
88 817	162		8.88 947	163	1.11 052	9.99 870	34				
88 980	162		8.89 111	163	1.10 889	9.99 869	33				
89 142	161		8.89 274	162	1.10 726	9.99 868	32				
89 303	161		8.89 436	162	1.10 563	9.99 867	31				
89 464	160		8.89 598	161	1.10 401	9.99 866	30				
89 624	159		8.89 759	161	1.10 240	9.99 865	29				
89 784	159		8.89 920	160	1.10 079	9.99 864	28				
89 943	158		8.90 080	159	1.09 919	9.99 863	27				
90 101	158		8.90 240	158	1.09 760	9.99 862	26				
90 259	157		8.90 398	158	1.09 601	9.99 861	25				
90 417	156		8.90 557	157	1.09 443	9.99 860	24				
90 573	156		8.90 714	157	1.09 285	9.99 859	23				
90 729	156		8.90 872	156	1.09 128	9.99 858	22				
90 885	155		8.91 028	156	1.08 971	9.99 857	21				
91 040	154		8.91 184	155	1.08 815	9.99 856	20				
91 195	154		8.91 340	155	1.08 660	9.99 855	19				
91 349	153		8.91 495	154	1.08 505	9.99 853	18				
91 502	153		8.91 649	154	1.08 350	9.99 852	17				
91 655	152		8.91 803	153	1.08 196	9.99 851	16				
91 807	152		8.91 957	152	1.08 043	9.99 850	15				
91 959	151		8.92 109	152	1.07 890	9.99 849	14				
92 110	150		8.92 262	151	1.07 738	9.99 848	13				
92 261	150		8.92 413	151	1.07 586	9.99 847	12				
92 411	149		8.92 565	150	1.07 435	9.99 846	11				
92 561	148		8.92 715	149	1.07 284	9.99 845	10				
92 710	148		8.92 866	149	1.07 134	9.99 844	9				
92 858	147		8.93 015	149	1.06 984	9.99 843	8				
93 007	147		8.93 164	148	1.06 835	9.99 842	7				
93 154	146		8.93 313	148	1.06 686	9.99 841	6				
93 301	146		8.93 461	147	1.06 538	9.99 840	5				
93 448	145		8.93 609	146	1.06 390	9.99 839	4				
93 594	145		8.93 756	146	1.06 243	9.99 837	3				
93 740	144		8.93 903	145	1.06 097	9.99 836	2				
93 885	144		8.94 049	145	1.05 950	9.99 835	1				
94 029			8.94 195		1.05 805	9.99 834	0				
Log. Cos.	d.		Log. Cot.	c. d.	Log. Tan.	Log. Sin.		P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

5°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.				
0	8.94 026	144	8 15	143	1.05 805	9.99 834	60					
1	8.94 174	143	8 5	144	1.05 659	9.99 833	59					
2	8.94 317	143	8 5	144	1.05 515	9.99 832	58					
3	8.94 460	143	8 5	144	1.05 370	9.99 831	57					
4	8.94 603	143	8 3	144	1.05 226	9.99 830	56					
5	8.94 745	142	8 7	143	1.05 083	9.99 829	55					
6	8.94 887	142	8.95 059	142	1.04 940	9.99 827	54					
7	8.95 028	141	8.95 202	142	1.04 798	9.99 826	53					
8	8.95 169	141	8.95 344	142	1.04 656	9.99 825	52					
9	8.95 310	140	8.95 485	141	1.04 514	9.99 824	51					
10	8.95 450	139	8.95 626	141	1.04 373	9.99 823	50					
11	8.95 589	139	8.95 767	140	1.04 232	9.99 822	49					
12	8.95 728	138	8.95 909	140	1.04 092	9.99 821	48					
13	8.95 867	138	8.96 047	139	1.03 952	9.99 819	47					
14	8.96 005	138	8.96 186	139	1.03 813	9.99 818	46					
15	8.96 143	137	8.96 325	138	1.03 674	9.99 817	45					
16	8.96 280	137	8.96 464	138	1.03 536	9.99 816	44					
17	8.96 417	137	8.96 602	138	1.03 398	9.99 815	43					
18	8.96 553	136	8.96 739	137	1.03 260	9.99 814	42					
19	8.96 689	136	8.96 876	137	1.03 123	9.99 813	41					
20	8.96 825	135	8.97 013	136	1.02 986	9.99 811	40					
21	8.96 960	134	8.97 149	136	1.02 850	9.99 810	39					
22	8.97 094	134	8.97 285	135	1.02 714	9.99 809	38					
23	8.97 229	134	8.97 421	135	1.02 579	9.99 808	37					
24	8.97 363	133	8.97 556	134	1.02 444	9.99 807	36					
25	8.97 496	133	8.97 690	134	1.02 309	9.99 805	35					
26	8.97 629	132	8.97 825	133	1.02 175	9.99 804	34					
27	8.97 762	132	8.97 958	133	1.02 041	9.99 803	33					
28	8.97 894	132	8.98 092	133	1.01 908	9.99 802	32					
29	8.98 026	131	8.98 225	132	1.01 775	9.99 801	31					
30	8.98 157	131	8.98 357	132	1.01 642	9.99 799	30					
31	8.98 288	130	8.98 490	131	1.01 510	9.99 798	29					
32	8.98 419	130	8.98 621	131	1.01 378	9.99 797	28					
33	8.98 549	130	8.98 753	131	1.01 247	9.99 796	27					
34	8.98 679	129	8.98 884	131	1.01 116	9.99 794	26					
35	8.98 808	129	8.99 015	130	1.00 985	9.99 793	25					
36	8.98 937	128	8.99 145	130	1.00 855	9.99 792	24					
37	8.99 066	128	8.99 275	129	1.00 725	9.99 791	23					
38	8.99 194	127	8.99 404	129	1.00 595	9.99 789	22					
39	8.99 322	127	8.99 533	129	1.00 466	9.99 788	21					
40	8.99 449	127	8.99 662	128	1.00 337	9.99 787	20					
41	8.99 577	126	8.99 791	128	1.00 209	9.99 786	19					
42	8.99 703	126	8.99 919	127	1.00 081	9.99 784	18					
43	8.99 830	126	9.00 046	127	0.99 953	9.99 783	17					
44	8.99 956	125	9.00 174	126	0.99 826	9.99 782	16					
45	9.00 081	125	9.00 300	126	0.99 699	9.99 781	15					
46	9.00 207	125	9.00 427	126	0.99 573	9.99 779	14					
47	9.00 332	124	9.00 553	125	0.99 446	9.99 778	13					
48	9.00 456	124	9.00 679	125	0.99 321	9.99 777	12					
49	9.00 580	124	9.00 804	125	0.99 195	9.99 776	11					
50	9.00 704	123	9.00 930	124	0.99 070	9.99 774	10					
51	9.00 828	123	9.01 054	124	0.98 945	9.99 773	9					
52	9.00 951	122	9.01 179	124	0.98 821	9.99 772	8					
53	9.01 073	122	9.01 303	124	0.98 697	9.99 770	7					
54	9.01 196	122	9.01 427	123	0.98 573	9.99 769	6					
55	9.01 318	122	9.01 550	123	0.98 450	9.99 768	5					
56	9.01 440	121	9.01 673	123	0.98 327	9.99 766	4					
57	9.01 561	121	9.01 796	122	0.98 204	9.99 765	3					
58	9.01 682	120	9.01 918	122	0.98 081	9.99 764	2					
59	9.01 803	120	9.02 040	121	0.97 959	9.99 763	1					
60	9.01 923		9.02 162		0.97 838	9.99 761	0					
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.						

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
6°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.				
0	9.01 923̄	120	9.02 162	121̄	0.97 838	9.99 761̄	60					
1	9.02 043̄	119̄	9.02 283̄	121̄	0.97 716̄	9.99 760	59					
2	9.02 163̄	119̄	9.02 404̄	120̄	0.97 595̄	9.99 759	58					
3	9.02 282̄	119̄	9.02 525̄	120̄	0.97 475̄	9.99 757̄	57					
4	9.02 401̄	119̄	9.02 645̄	120̄	0.97 354̄	9.99 756	56					
5	9.02 520̄	118̄	9.02 765̄	119̄	0.97 234̄	9.99 754̄	55					
6	9.02 638̄	118̄	9.02 885̄	119̄	0.97 115̄	9.99 753̄	54					
7	9.02 756̄	118̄	9.03 004̄	119̄	0.96 995̄	9.99 752	53					
8	9.02 874̄	117̄	9.03 123̄	119̄	0.96 876̄	9.99 750̄	52					
9	9.02 992̄	117̄	9.03 242̄	118̄	0.96 757̄	9.99 749̄	51					
10	9.03 109̄	116̄	9.03 361̄	118̄	0.96 639̄	9.99 748	50					
11	9.03 225̄	116̄	9.03 479̄	118̄	0.96 521̄	9.99 746̄	49					
12	9.03 342̄	116̄	9.03 597̄	117̄	0.96 403̄	9.99 745	48					
13	9.03 458̄	115̄	9.03 714̄	117̄	0.96 285̄	9.99 744̄	47					
14	9.03 574̄	115̄	9.03 831̄	116̄	0.96 168̄	9.99 742̄	46					
15	9.03 689̄	114̄	9.03 948̄	116̄	0.96 051̄	9.99 741̄	45					
16	9.03 805̄	114̄	9.04 065̄	116̄	0.95 935̄	9.99 739̄	44					
17	9.03 919̄	114̄	9.04 181̄	116̄	0.95 818̄	9.99 738̄	43					
18	9.04 034̄	114̄	9.04 297̄	115̄	0.95 702̄	9.99 737̄	42					
19	9.04 148̄	114̄	9.04 413̄	115̄	0.95 587̄	9.99 735̄	41					
20	9.04 262̄	113̄	9.04 528̄	115̄	0.95 471̄	9.99 734̄	40					
21	9.04 376̄	113̄	9.04 643̄	114̄	0.95 356̄	9.99 732̄	39					
22	9.04 489̄	113̄	9.04 758̄	114̄	0.95 242̄	9.99 731̄	38					
23	9.04 602̄	112̄	9.04 872̄	114̄	0.95 127̄	9.99 730̄	37					
24	9.04 715̄	112̄	9.04 987̄	114̄	0.95 013̄	9.99 728̄	36					
25	9.04 828̄	112̄	9.05 101̄	113̄	0.94 899̄	9.99 727̄	35					
26	9.04 940̄	112̄	9.05 214̄	113̄	0.94 785̄	9.99 725̄	34					
27	9.05 052̄	111̄	9.05 327̄	113̄	0.94 672̄	9.99 724̄	33					
28	9.05 163̄	111̄	9.05 440̄	113̄	0.94 559̄	9.99 723̄	32					
29	9.05 275̄	111̄	9.05 553̄	112̄	0.94 446̄	9.99 721̄	31					
30	9.05 386̄	110̄	9.05 666̄	112̄	0.94 334̄	9.99 720̄	30					
31	9.05 496̄	110̄	9.05 778̄	112̄	0.94 222̄	9.99 718̄	29					
32	9.05 607̄	110̄	9.05 890̄	111̄	0.94 110̄	9.99 717̄	28					
33	9.05 717̄	110̄	9.06 001̄	111̄	0.93 998̄	9.99 715̄	27					
34	9.05 827̄	109̄	9.06 113̄	111̄	0.93 887̄	9.99 714̄	26					
35	9.05 936̄	109̄	9.06 224̄	111̄	0.93 776̄	9.99 712̄	25					
36	9.06 046̄	109̄	9.06 335̄	110̄	0.93 665̄	9.99 711̄	24					
37	9.06 155̄	109̄	9.06 445̄	110̄	0.93 554̄	9.99 710̄	23					
38	9.06 264̄	108̄	9.06 555̄	110̄	0.93 444̄	9.99 708̄	22					
39	9.06 372̄	108̄	9.06 665̄	109̄	0.93 334̄	9.99 707̄	21					
40	9.06 480̄	108̄	9.06 775̄	109̄	0.93 225̄	9.99 705̄	20					
41	9.06 588̄	107̄	9.06 884̄	109̄	0.93 115̄	9.99 704̄	19					
42	9.06 696̄	107̄	9.06 994̄	108̄	0.93 006̄	9.99 702̄	18					
43	9.06 803̄	107̄	9.07 102̄	108̄	0.92 897̄	9.99 701̄	17					
44	9.06 910̄	107̄	9.07 211̄	109̄	0.92 788̄	9.99 699̄	16					
45	9.07 017̄	106̄	9.07 319̄	108̄	0.92 680̄	9.99 698̄	15					
46	9.07 124̄	106̄	9.07 428̄	107̄	0.92 572̄	9.99 696̄	14					
47	9.07 230̄	106̄	9.07 535̄	107̄	0.92 464̄	9.99 695̄	13					
48	9.07 336̄	106̄	9.07 643̄	107̄	0.92 357̄	9.99 693̄	12					
49	9.07 442̄	105̄	9.07 750̄	107̄	0.92 249̄	9.99 692̄	11					
50	9.07 548̄	105̄	9.07 857̄	107̄	0.92 142̄	9.99 690̄	10					
51	9.07 653̄	105̄	9.07 964̄	106̄	0.92 035̄	9.99 689̄	9					
52	9.07 758̄	104̄	9.08 071̄	106̄	0.91 929̄	9.99 687̄	8					
53	9.07 863̄	104̄	9.08 177̄	106̄	0.91 822̄	9.99 686̄	7					
54	9.07 967̄	104̄	9.08 283̄	105̄	0.91 716̄	9.99 684̄	6					
55	9.08 072̄	104̄	9.08 389̄	105̄	0.91 611̄	9.99 683̄	5					
56	9.08 176̄	103̄	9.08 494̄	105̄	0.91 505̄	9.99 681̄	4					
57	9.08 279̄	103̄	9.08 600̄	105̄	0.91 400̄	9.99 679̄	3					
58	9.08 383̄	103̄	9.08 705̄	105̄	0.91 295̄	9.99 678̄	2					
59	9.08 486̄	103̄	9.08 810̄	104̄	0.91 190̄	9.99 676̄	1					
60	9.08 589̄	103̄	9.08 914̄	104̄	0.91 085̄	9.99 675̄	0					
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.		P. P.				

121̄ 121̄ 120 119 118

6 12.1̄ 12.1̄ 12.0 11.9 11.8

7 14.2̄ 14.1̄ 14.0 13.9 13.8

8 16.2̄ 16.1̄ 16.0 15.9 15.8

9 18.2̄ 18.1̄ 18.0 17.9 17.8

10 20.2̄ 20.1̄ 20.0 19.9 19.8

20 40.5̄ 40.3̄ 40.0 39.6 39.3

30 60.7̄ 60.5̄ 60.0 59.5 59.0

40 81.0̄ 80.6̄ 80.0 79.4 78.8

50 101.2̄ 100.8̄ 100.0 99.1 98.3

117 117 116 115

6 11.7̄ 11.7̄ 11.6 11.5

7 13.7̄ 13.6̄ 13.5 13.4

8 15.6̄ 15.6̄ 15.4 15.3

9 17.6̄ 17.5̄ 17.4 17.3

10 19.6̄ 19.5̄ 19.3 19.1

20 39.1̄ 39.0̄ 38.6 38.3

30 58.7̄ 58.5̄ 58.0 57.5

40 78.3̄ 78.0̄ 77.3 76.7

50 97.9̄ 97.5̄ 96.6 95.8

114 114 113 112 111

6 11.4̄ 11.4̄ 11.3 11.2 11.1

7 13.3̄ 13.3̄ 13.2 13.0 12.9

8 15.2̄ 15.2̄ 15.0 14.9 14.7

9 17.2̄ 17.1̄ 16.9 16.8 16.6

10 19.1̄ 19.0̄ 18.8 18.6 18.5

20 38.1̄ 38.0̄ 37.6 37.3 37.0

30 57.2̄ 57.0̄ 56.5 56.0 55.5

40 76.3̄ 76.0̄ 75.3 74.6 74.1

50 95.4̄ 95.0̄ 94.1 93.3 92.5

110 110 109 108

6 11.0̄ 11.0̄ 10.9 10.8

7 12.9̄ 12.8̄ 12.7 12.6

8 14.7̄ 14.6̄ 14.5 14.4

9 16.6̄ 16.5̄ 16.3 16.2

10 18.4̄ 18.3̄ 18.1 18.0

20 36.8̄ 36.6̄ 36.3 36.0

30 55.2̄ 55.0̄ 54.5 54.0

40 73.6̄ 73.3̄ 72.6 72.0

50 92.1̄ 91.6̄ 90.8 90.0

107 107 106 105 104

6 10.7̄ 10.7̄ 10.6 10.5 10.4

7 12.5̄ 12.5̄ 12.3 12.2 12.1

8 14.3̄ 14.2̄ 14.1 14.0 13.8

9 16.1̄ 16.0̄ 15.9 15.7 15.6

10 17.9̄ 17.8̄ 17.6 17.5 17.3

20 35.8̄ 35.6̄ 35.3 35.0 34.7

30 53.7̄ 53.5̄ 53.0 52.5 52.0

40 71.6̄ 71.3̄ 70.6 70.0 69.3

50 89.6̄ 89.1̄ 88.3 87.5 86.6

103 103 2 1 1

6 10.3̄ 10.3̄ 0.2̄ 0.1̄ 0.1̄

7 12.1̄ 12.0̄ 0.2̄ 0.2̄ 0.1̄

8 13.8̄ 13.7̄ 0.2̄ 0.2̄ 0.1̄

9 15.5̄ 15.4̄ 0.2̄ 0.2̄ 0.1̄

10 17.2̄ 17.1̄ 0.2̄ 0.2̄ 0.1̄

20 34.5̄ 34.3̄ 0.6̄ 0.5̄ 0.3̄

30 51.7̄ 51.5̄ 1.0̄ 0.9̄ 0.7̄

40 69.0̄ 68.6̄ 1.3̄ 1.0̄ 0.8̄

50 86.2̄ 85.8̄ 1.6̄ 1.2̄ 0.8̄

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

7°

'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.				
0	9.08 589	102	9.08 914	104	0.91 085	9.99 675	60					
1	9.08 692	102	9.09 018	104	0.90 981	9.99 673	59					
2	9.08 794	102	9.09 123	104	0.90 877	9.99 672	58					
3	9.08 897	102	9.09 226	103	0.90 773	9.99 670	57					
4	9.08 999	102	9.09 330	103	0.90 670	9.99 669	56					
5	9.09 101	102	9.09 433	103	0.90 566	9.99 667	55					
6	9.09 202	101	9.09 536	103	0.90 463	9.99 665	54					
7	9.09 303	101	9.09 639	103	0.90 360	9.99 664	53					
8	9.09 404	101	9.09 742	102	0.90 258	9.99 662	52					
9	9.09 505	101	9.09 844	102	0.90 155	9.99 661	51					
10	9.09 606	100	9.09 947	101	0.90 053	9.99 659	50					
11	9.09 706	100	9.10 048	102	0.89 951	9.99 658	49					
12	9.09 806	100	9.10 150	101	0.89 849	9.99 656	48					
13	9.09 906	99	9.10 252	101	0.89 748	9.99 654	47					
14	9.10 006	99	9.10 353	101	0.89 647	9.99 653	46					
15	9.10 105	99	9.10 454	101	0.89 546	9.99 651	45					
16	9.10 205	99	9.10 555	101	0.89 445	9.99 650	44					
17	9.10 303	98	9.10 655	100	0.89 344	9.99 648	43					
18	9.10 402	99	9.10 756	100	0.89 244	9.99 646	42					
19	9.10 501	98	9.10 856	100	0.89 144	9.99 645	41					
20	9.10 599	98	9.10 956	100	0.89 044	9.99 643	40					
21	9.10 697	98	9.11 055	99	0.88 944	9.99 641	39					
22	9.10 795	97	9.11 155	99	0.88 845	9.99 640	38					
23	9.10 892	97	9.11 254	99	0.88 745	9.99 638	37					
24	9.10 990	97	9.11 353	99	0.88 646	9.99 637	36					
25	9.11 089	97	9.11 452	98	0.88 548	9.99 635	35					
26	9.11 184	96	9.11 550	98	0.88 449	9.99 633	34					
27	9.11 281	97	9.11 649	98	0.88 351	9.99 632	33					
28	9.11 379	96	9.11 747	98	0.88 253	9.99 630	32					
29	9.11 473	96	9.11 845	98	0.88 155	9.99 628	31					
30	9.11 570	96	9.11 943	98	0.88 057	9.99 627	30					
31	9.11 665	95	9.12 040	97	0.87 959	9.99 625	29					
32	9.11 761	96	9.12 137	97	0.87 862	9.99 623	28					
33	9.11 856	95	9.12 235	97	0.87 765	9.99 622	27					
34	9.11 952	95	9.12 331	96	0.87 668	9.99 620	26					
35	9.12 047	95	9.12 428	97	0.87 571	9.99 618	25					
36	9.12 141	94	9.12 525	96	0.87 475	9.99 617	24					
37	9.12 236	94	9.12 621	96	0.87 379	9.99 615	23					
38	9.12 330	94	9.12 717	96	0.87 283	9.99 613	22					
39	9.12 425	94	9.12 813	96	0.87 187	9.99 611	21					
40	9.12 518	93	9.12 908	95	0.87 091	9.99 610	20					
41	9.12 612	94	9.13 004	95	0.86 996	9.99 608	19					
42	9.12 706	93	9.13 099	95	0.86 900	9.99 606	18					
43	9.12 799	93	9.13 194	95	0.86 805	9.99 605	17					
44	9.12 892	93	9.13 289	95	0.86 710	9.99 603	16					
45	9.12 985	93	9.13 384	94	0.86 616	9.99 601	15					
46	9.13 078	92	9.13 478	94	0.86 521	9.99 600	14					
47	9.13 170	92	9.13 572	94	0.86 427	9.99 598	13					
48	9.13 263	92	9.13 666	94	0.86 333	9.99 596	12					
49	9.13 355	92	9.13 760	94	0.86 239	9.99 594	11					
50	9.13 447	91	9.13 854	93	0.86 146	9.99 593	10					
51	9.13 538	92	9.13 947	93	0.86 052	9.99 591	9					
52	9.13 630	91	9.14 041	93	0.85 959	9.99 589	8					
53	9.13 721	91	9.14 134	93	0.85 866	9.99 587	7					
54	9.13 813	90	9.14 227	93	0.85 773	9.99 586	6					
55	9.13 903	90	9.14 319	92	0.85 680	9.99 584	5					
56	9.13 994	90	9.14 412	92	0.85 588	9.99 582	4					
57	9.14 085	90	9.14 504	92	0.85 495	9.99 580	3					
58	9.14 175	90	9.14 596	92	0.85 403	9.99 579	2					
59	9.14 265	90	9.14 688	92	0.85 311	9.99 577	1					
60	9.14 355	90	9.14 780	92	0.85 219	9.99 575	0					
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	'	P. P.				

sin	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.			
355	90	9.14 786	91	0.85 216	9.99 575	60				
445	89	9.14 872	91	0.85 128	9.99 573	59				
535	89	9.14 963	91	0.85 037	9.99 571	58				
624	89	9.15 054	91	0.84 945	9.99 570	57				
713	89	9.15 145	91	0.84 854	9.99 568	56				
802	89	9.15 236	91	0.84 763	9.99 566	55				
891	88	9.15 327	90	0.84 673	9.99 564	54				
980	88	9.15 417	90	0.84 582	9.99 563	53				
068	88	9.15 507	90	0.84 492	9.99 561	52				
157	88	9.15 598	89	0.84 402	9.99 559	51				
245	88	9.15 689	90	0.84 312	9.99 557	50				
333	88	9.15 779	89	0.84 222	9.99 555	49				
421	87	9.15 867	89	c 3	9.99 553	48				
508	87	9.15 956	89	c 3	9.99 552	47				
595	87	9.16 045	89	c 4	9.99 550	46				
683	87	9.16 134	89	c 5	9.99 548	45				
770	87	9.16 223	89	c 6	9.99 546	44				
857	86	9.16 312	88	c 7	9.99 544	43				
943	86	9.16 401	88	c 9	9.99 542	42				
030	86	9.16 489	88	c 3.1	9.99 541	41				
116	86	9.16 577	88	0.83 422	9.99 539	40				
202	86	9.16 665	87	0.83 334	9.99 537	39				
288	86	9.16 753	88	0.83 247	9.99 535	38				
374	85	9.16 841	87	0.83 159	9.99 533	37				
460	85	9.16 928	87	0.83 071	9.99 531	36				
545	85	9.17 015	87	0.82 984	9.99 529	35				
630	85	9.17 103	87	0.82 897	9.99 528	34				
716	85	9.17 190	86	0.82 810	9.99 526	33				
801	84	9.17 276	87	0.82 723	9.99 524	32				
885	84	9.17 363	86	0.82 636	9.99 522	31				
970	84	9.17 450	86	0.82 550	9.99 520	30				
054	84	9.17 536	86	0.82 464	9.99 518	29				
139	84	9.17 622	86	0.82 377	9.99 516	28				
223	84	9.17 708	85	0.82 291	9.99 514	27				
307	84	9.17 794	86	0.82 206	9.99 512	26				
391	83	9.17 880	85	0.82 120	9.99 511	25				
474	83	9.17 965	85	0.82 034	9.99 509	24				
558	83	9.18 051	85	0.81 949	9.99 507	23				
641	83	9.18 136	85	0.81 864	9.99 505	22				
724	83	9.18 221	85	0.81 779	9.99 503	21				
807	83	9.18 306	84	0.81 694	9.99 501	20				
890	82	9.18 390	84	0.81 609	9.99 499	19				
972	82	9.18 475	84	0.81 525	9.99 497	18				
055	82	9.18 559	84	0.81 440	9.99 495	17				
137	82	9.18 644	84	0.81 356	9.99 493	16				
219	82	9.18 728	84	0.81 272	9.99 491	15				
301	82	9.18 812	84	0.81 188	9.99 489	14				
383	81	9.18 896	83	0.81 104	9.99 487	13				
465	81	9.18 979	83	0.81 020	9.99 485	12				
546	81	9.19 063	83	0.80 937	9.99 484	11				
628	81	9.19 146	83	0.80 854	9.99 482	10				
709	81	9.19 229	83	0.80 770	9.99 480	9				
790	80	9.19 312	83	0.80 687	9.99 478	8				
871	81	9.19 395	82	0.80 604	9.99 476	7				
952	80	9.19 478	82	0.80 522	9.99 474	6				
032	80	9.19 560	82	0.80 439	9.99 472	5				
113	80	9.19 643	82	0.80 357	9.99 470	4				
193	80	9.19 725	82	0.80 274	9.99 468	3				
273	80	9.19 807	82	0.80 192	9.99 466	2				
353	79	9.19 889	82	0.80 110	9.99 464	1				
433	79	9.19 971	82	0.80 028	9.99 462	0				
Con.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.		P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

9°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.			
0	9.19 433	80	9.19 971	81	0.80 028	9.99 462	60				
1	9.19 513	79	9.20 053	81	0.79 947	9.99 460	59				
2	9.19 592	79	9.20 134	81	0.79 865	9.99 458	58				
3	9.19 672	79	9.20 216	81	0.79 784	9.99 456	57				
4	9.19 751	79	9.20 297	81	0.79 703	9.99 454	56				
5	9.19 830	79	9.20 378	81	0.79 622	9.99 452	55				
6	9.19 909	79	9.20 459	81	0.79 541	9.99 450	54				
7	9.19 988	79	9.20 540	81	0.79 460	9.99 448	53				
8	9.20 066	78	9.20 620	80	0.79 379	9.99 446	52				
9	9.20 145	78	9.20 701	81	0.79 298	9.99 444	51				
10	9.20 223	78	9.20 781	80	0.79 218	9.99 442	50				
11	9.20 301	78	9.20 862	80	0.79 138	9.99 440	49				
12		78	9.20 942	80	0.79 058	9.99 437	48				
13		78	9.21 022	80	0.78 978	9.99 435	47				
14		78	9.21 102	80	0.78 898	9.99 433	46				
15		77	9.21 181	79	0.78 818	9.99 431	45				
16		77	9.21 261	79	0.78 739	9.99 429	44				
17		77	9.21 340	79	0.78 659	9.99 427	43				
18		77	9.21 420	79	0.78 580	9.99 425	42				
19		77	9.21 499	79	0.78 501	9.99 423	41				
20	9.20 999	77	9.21 578	79	0.78 422	9.99 421	40				
21	9.21 076	77	9.21 657	79	0.78 343	9.99 419	39				
22	9.21 152	76	9.21 735	78	0.78 264	9.99 417	38				
23	9.21 229	76	9.21 814	78	0.78 186	9.99 415	37				
24	9.21 305	76	9.21 892	78	0.78 107	9.99 413	36				
25	9.21 382	76	9.21 971	78	0.78 029	9.99 411	35				
26	9.21 458	76	9.22 049	78	0.77 951	9.99 408	34				
27	9.21 534	76	9.22 127	78	0.77 873	9.99 406	33				
28	9.21 609	75	9.22 205	78	0.77 795	9.99 404	32				
29	9.21 685	76	9.22 283	78	0.77 717	9.99 402	31				
30	9.21 761	75	9.22 360	77	0.77 639	9.99 400	30				
31	9.21 836	75	9.22 438	77	0.77 562	9.99 398	29				
32	9.21 911	75	9.22 515	77	0.77 484	9.99 396	28				
33	9.21 987	75	9.22 593	77	0.77 407	9.99 394	27				
34	9.22 062	75	9.22 670	77	0.77 330	9.99 392	26				
35	9.22 136	74	9.22 747	77	0.77 253	9.99 389	25				
36	9.22 211	75	9.22 824	77	0.77 176	9.99 387	24				
37	9.22 286	74	9.22 900	76	0.77 099	9.99 385	23				
38	9.22 360	74	9.22 977	77	0.77 022	9.99 383	22				
39	9.22 435	74	9.23 054	76	0.76 946	9.99 381	21				
40	9.22 509	74	9.23 130	76	0.76 870	9.99 379	20				
41	9.22 583	74	9.23 206	76	0.76 793	9.99 377	19				
42	9.22 657	74	9.23 283	76	0.76 717	9.99 374	18				
43	9.22 731	73	9.23 358	76	0.76 641	9.99 372	17				
44	9.22 805	74	9.23 434	76	0.76 565	9.99 370	16				
45	9.22 878	73	9.23 510	76	0.76 489	9.99 368	15				
46	9.22 952	73	9.23 586	75	0.76 414	9.99 366	14				
47	9.23 025	73	9.23 661	75	0.76 338	9.99 364	13				
48	9.23 098	73	9.23 737	75	0.76 263	9.99 361	12				
49	9.23 171	73	9.23 812	75	0.76 188	9.99 359	11				
50	9.23 244	73	9.23 887	75	0.76 113	9.99 357	10				
51	9.23 317	72	9.23 962	75	0.76 038	9.99 355	9				
52	9.23 390	73	9.24 037	75	0.75 963	9.99 353	8				
53	9.23 462	72	9.24 112	75	0.75 888	9.99 350	7				
54	9.23 535	72	9.24 186	74	0.75 813	9.99 348	6				
55	9.23 607	72	9.24 261	74	0.75 739	9.99 346	5				
56	9.23 679	72	9.24 335	74	0.75 664	9.99 344	4				
57	9.23 751	72	9.24 409	74	0.75 590	9.99 342	3				
58	9.23 823	72	9.24 484	74	0.75 516	9.99 339	2				
59	9.23 895	72	9.24 558	74	0.75 442	9.99 337	1				
60	9.23 967	71	9.24 632	74	0.75 368	9.99 335	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.					

P. P.			
	81	81	80
6	8.1	8.1	8.0
7	9.5	9.4	9.3
8	10.8	10.8	10.6
9	12.2	12.1	12.0
10	13.6	13.5	13.3
20	27.1	27.0	26.6
30	40.7	40.5	40.0
40	54.3	54.0	53.3
50	67.9	67.5	66.6

P. P.			
	78	78	77
6	7.8	7.8	7.7
7	9.1	9.1	9.0
8	10.4	10.4	10.2
9	11.8	11.7	11.5
10	13.1	13.0	12.8
20	26.1	26.0	25.6
30	39.2	39.0	38.5
40	52.3	52.0	51.3
50	65.4	65.0	64.1

P. P.			
	76	76	75
6	7.6	7.6	7.5
7	8.9	8.8	8.7
8	10.2	10.1	10.0
9	11.5	11.4	11.2
10	12.7	12.6	12.5
20	25.5	25.3	25.0
30	38.2	38.0	37.5
40	51.0	50.6	50.0
50	63.7	63.3	62.5

P. P.			
	73	73	72
6	7.3	7.3	7.2
7	8.6	8.5	8.4
8	9.8	9.7	9.6
9	11.0	10.9	10.8
10	12.2	12.1	12.0
20	24.5	24.3	24.0
30	36.7	36.5	36.0
40	49.0	48.6	48.0
50	61.2	60.8	60.0

P. P.			
	71	71	70
6	7.1	7.1	7.0
7	8.3	8.3	8.2
8	9.5	9.4	9.3
9	10.7	10.6	10.5
10	11.9	11.8	11.7
20	23.8	23.6	23.5
30	35.7	35.5	35.4
40	47.6	47.3	47.2
50	59.6	59.1	58.9

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

10°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.			
0	9.23 967	71	9.24 632	73	0.75 368	9.99 335	60				
1	9.24 038	71	9.24 705	74	0.75 294	9.99 333	59	74	73	73	
2	9.24 110	71	9.24 779	73	0.75 220	9.99 330	58	6	7.4	7.3	7.3
3	9.24 181	71	9.24 853	73	0.75 147	9.99 328	57	7	8.6	8.6	8.5
4	9.24 252	71	9.24 926	73	0.75 073	9.99 326	56	8	9 8	9 8	9.7
5	9.24 323	71	9.25 000	73	0.75 000	9.99 324	55	9	11.1	11.0	10.9
6	9.24 394	71	9.25 073	73	0.74 927	9.99 321	54	10	12.3	12.2	12.1
7	9.24 465	71	9.25 146	73	0.74 854	9.99 319	53	20	24.6	24.5	24.3
8	9.24 536	70	9.25 219	73	0.74 781	9.99 317	52	30	37.0	36.7	36.5
9	9.24 607	70	9.25 292	73	0.74 708	9.99 315	51	40	49.3	49.0	48.6
10	9.24 677	70	9.25 365	72	0.74 635	9.99 312	50	50	61.6	61.2	60.8
11	9.24 748	70	9.25 437	72	0.74 562	9.99 310	49	72	72	72	71
12	9.24 818	70	9.25 510	72	0.74 490	9.99 308	48	6	7.3	7.2	7.1
13	9.24 888	70	9.25 582	72	0.74 417	9.99 306	47	7	8.4	8.4	8.3
14	9.24 958	69	9.25 654	72	0.74 345	9.99 303	46	8	9.6	9.6	9.5
15	9.25 028	70	9.25 727	72	0.74 273	9.99 301	45	9	10.9	10.8	10.7
16	9.25 098	69	9.25 799	72	0.74 201	9.99 299	44	10	12.1	12.0	11.9
17	9.25 169	70	9.25 871	72	0.74 129	9.99 296	43	20	24.1	24.0	23.8
18	9.25 237	69	9.25 943	71	0.74 057	9.99 294	42	30	36.2	36.0	35.7
19	9.25 306	69	9.26 014	72	0.73 985	9.99 292	41	40	48.3	48.0	47.6
20	9.25 376	69	9.26 086	71	0.73 913	9.99 290	40	50	60.4	60.0	59.6
21	9.25 445	69	9.26 158	71	0.73 842	9.99 287	39	70	70	69	69
22	9.25 514	69	9.26 229	71	0.73 771	9.99 285	38	6	7.6	7.0	6.9
23	9.25 583	69	9.26 300	71	0.73 699	9.99 283	37	7	8.2	8.1	8.0
24	9.25 652	68	9.26 371	71	0.73 628	9.99 280	36	8	9.4	9.3	9.2
25	9.25 721	69	9.26 443	71	0.73 557	9.99 278	35	9	10.6	10.5	10.4
26	9.25 790	68	9.26 514	70	0.73 486	9.99 276	34	10	11.7	11.6	11.5
27	9.25 858	68	9.26 585	71	0.73 415	9.99 273	33	20	23.5	23.3	23.1
28	9.25 927	68	9.26 656	70	0.73 344	9.99 271	32	30	35.2	35.0	34.7
29	9.25 995	68	9.26 727	70	0.73 274	9.99 269	31	40	47.0	46.6	46.3
30	9.26 063	68	9.26 798	70	0.73 203	9.99 266	30	50	58.7	58.3	57.9
31	9.26 131	68	9.26 869	70	0.73 133	9.99 264	29	68	68	67	67
32	9.26 199	68	9.26 940	70	0.73 062	9.99 262	28	6	6.8	6.8	6.7
33	9.26 267	67	9.27 009	70	0.72 992	9.99 259	27	7	8.0	7.9	7.8
34	9.26 335	67	9.27 078	70	0.72 922	9.99 257	26	8	9.1	9.0	8.9
35	9.26 402	68	9.27 148	70	0.72 852	9.99 255	25	9	10.3	10.2	10.1
36	9.26 470	67	9.27 218	69	0.72 782	9.99 252	24	10	11.4	11.3	11.2
37	9.26 537	67	9.27 287	70	0.72 712	9.99 250	23	20	22.8	22.6	22.5
38	9.26 605	67	9.27 357	69	0.72 642	9.99 248	22	30	34.2	34.0	33.7
39	9.26 672	67	9.27 427	69	0.72 573	9.99 245	21	40	45.6	45.3	45.0
40	9.26 739	67	9.27 496	69	0.72 503	9.99 243	20	50	57.1	56.6	56.2
41	9.26 806	67	9.27 566	69	0.72 434	9.99 240	19	66	66	65	65
42	9.26 873	66	9.27 635	69	0.72 365	9.99 238	18	6	6.6	6.6	6.5
43	9.26 940	67	9.27 704	69	0.72 295	9.99 236	17	7	7.7	7.7	7.6
44	9.27 007	66	9.27 773	69	0.72 226	9.99 233	16	8	8.8	8.8	8.7
45	9.27 073	66	9.27 842	69	0.72 157	9.99 231	15	9	10.0	9.9	9.8
46	9.27 140	66	9.27 911	68	0.72 088	9.99 228	14	10	11.1	11.0	10.9
47	9.27 206	66	9.27 980	69	0.72 020	9.99 226	13	20	22.1	22.0	21.8
48	9.27 272	66	9.28 049	68	0.71 951	9.99 224	12	30	33.2	33.0	32.7
49	9.27 339	66	9.28 117	68	0.71 882	9.99 221	11	40	44.3	44.0	43.6
50	9.27 405	66	9.28 186	68	0.71 814	9.99 219	10	50	55.4	55.0	54.6
51	9.27 471	65	9.28 254	68	0.71 746	9.99 216	9				
52	9.27 536	66	9.28 322	68	0.71 677	9.99 214	8	6	0.2	0.2	
53	9.27 602	65	9.28 390	68	0.71 609	9.99 212	7	7	0.3	0.2	
54	9.27 668	65	9.28 459	68	0.71 541	9.99 209	6	8	0.3	0.2	
55	9.27 733	65	9.28 527	69	0.71 473	9.99 207	5	9	0.4	0.3	
56	9.27 799	65	9.28 594	68	0.71 405	9.99 204	4	10	0.4	0.3	
57	9.27 864	65	9.28 662	69	0.71 337	9.99 202	3	20	0.8	0.6	
58	9.27 929	65	9.28 730	69	0.71 270	9.99 199	2	30	1.2	1.0	
59	9.27 995	65	9.28 797	69	0.71 202	9.99 197	1	40	1.6	1.3	
60	9.28 060	65	9.28 865	69	0.71 135	9.99 194	0	50	2.1	1.6	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.		P. P.			

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78°

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

12°

'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.		P. P.			
								62	61	61	
0	9.31 788	59	9.32 747	62	0.67 252	9.99 040	60				
1	9.31 847	59	9.32 806	62	0.67 190	9.99 038	59				
2	9.31 906	59	9.32 871	62	0.67 128	9.99 035	58				
3	9.31 966	59	9.32 933	62	0.67 066	9.99 032	57				
4	9.32 025	59	9.32 995	61	0.67 004	9.99 029	56				
5	9.32 084	59	9.33 057	61	0.66 943	9.99 027	55				
6	9.32 143	59	9.33 118	62	0.66 881	9.99 024	54				
7	9.32 202	58	9.33 180	61	0.66 819	9.99 021	53				
8	9.32 260	58	9.33 242	61	0.66 758	9.99 019	52				
9	9.32 319	58	9.33 303	61	0.66 696	9.99 016	51				
10	9.32 378	58	9.33 364	61	0.66 635	9.99 013	50				
11	9.32 436	58	9.33 426	61	0.66 574	9.99 010	49				
12	9.32 495	58	9.33 487	61	0.66 513	9.99 008	48				
13	9.32 553	58	9.33 548	61	0.66 452	9.99 005	47				
14	9.32 611	58	9.33 609	60	0.66 390	9.99 002	46				
15	9.32 670	58	9.33 670	61	0.66 330	9.98 999	45				
16	9.32 728	58	9.33 731	61	0.66 269	9.98 997	44				
17	9.32 786	58	9.33 792	60	0.66 208	9.98 994	43				
18	9.32 844	58	9.33 852	61	0.66 147	9.98 991	42				
19	9.32 902	58	9.33 913	60	0.66 086	9.98 988	41				
20	9.32 960	57	9.33 974	60	0.66 026	9.98 986	40				
21	9.33 017	58	9.34 034	60	0.65 965	9.98 983	39				
22	9.33 075	57	9.34 095	60	0.65 905	9.98 980	38				
23	9.33 133	57	9.34 155	60	0.65 845	9.98 977	37				
24	9.33 190	57	9.34 215	60	0.65 784	9.98 975	36				
25	9.33 248	57	9.34 275	60	0.65 724	9.98 972	35				
26	9.33 305	57	9.34 336	60	0.65 664	9.98 969	34				
27	9.33 362	57	9.34 396	60	0.65 604	9.98 966	33				
28	9.33 419	57	9.34 456	59	0.65 544	9.98 963	32				
29	9.33 476	57	9.34 515	60	0.65 484	9.98 961	31				
30	9.33 533	57	9.34 575	60	0.65 424	9.98 958	30				
31	9.33 590	57	9.34 635	59	0.65 364	9.98 955	29				
32	9.33 647	57	9.34 695	59	0.65 305	9.98 952	28				
33	9.33 704	56	9.34 754	59	0.65 245	9.98 949	27				
34	9.33 761	56	9.34 814	59	0.65 186	9.98 947	26				
35	9.33 817	56	9.34 873	59	0.65 126	9.98 944	25				
36	9.33 874	56	9.34 933	59	0.65 067	9.98 941	24				
37	9.33 930	56	9.34 992	59	0.65 008	9.98 938	23				
38	9.33 987	56	9.35 051	59	0.64 948	9.98 935	22				
39	9.34 043	56	9.35 110	59	0.64 889	9.98 933	21				
40	9.34 099	56	9.35 169	59	0.64 830	9.98 930	20				
41	9.34 156	56	9.35 228	59	0.64 771	9.98 927	19				
42	9.34 212	56	9.35 287	59	0.64 712	9.98 924	18				
43	9.34 268	56	9.35 346	59	0.64 653	9.98 921	17				
44	9.34 324	55	9.35 405	58	0.64 594	9.98 918	16				
45	9.34 379	56	9.35 464	58	0.64 536	9.98 915	15				
46	9.34 435	55	9.35 522	59	0.64 477	9.98 913	14				
47	9.34 491	56	9.35 581	58	0.64 418	9.98 910	13				
48	9.34 547	55	9.35 640	58	0.64 360	9.98 907	12				
49	9.34 602	55	9.35 698	58	0.64 302	9.98 904	11				
50	9.34 658	55	9.35 756	58	0.64 243	9.98 901	10				
51	9.34 713	55	9.35 815	58	0.64 185	9.98 898	9				
52	9.34 768	55	9.35 873	58	0.64 127	9.98 895	8				
53	9.34 824	55	9.35 931	58	0.64 068	9.98 892	7				
54	9.34 879	55	9.35 989	58	0.64 010	9.98 890	6				
55	9.34 934	55	9.36 047	58	0.63 952	9.98 887	5				
56	9.34 989	55	9.36 105	57	0.63 894	9.98 884	4				
57	9.35 044	54	9.36 163	58	0.63 837	9.98 881	3				
58	9.35 099	55	9.36 221	57	0.63 779	9.98 878	2				
59	9.35 154	55	9.36 278	58	0.63 721	9.98 875	1				
60	9.35 209	55	9.36 336	58	0.63 663	9.98 872	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	'	P. P.			

6	6.2	6.1	6.1
7	7.2	7.2	7.1
8	8.2	8.2	8.1
9	9.3	9.2	9.1
10	10.3	10.2	10.1
20	20.6	20.5	20.3
30	31.0	30.7	30.5
40	41.3	41.0	40.6
50	51.6	51.2	50.8

6	6.0	6.0	5.9	5.9
7	7.0	7.0	6.9	6.9
8	8.0	8.0	7.9	7.8
9	9.0	9.0	8.9	8.8
10	10.0	10.0	9.9	9.8
20	20.0	20.0	19.8	19.6
30	30.0	30.0	29.7	29.5
40	40.0	39.6	39.3	39.1
50	50.0	49.6	49.1	

6	5.8	5.8	5.7	5.7
7	6.8	6.7	6.7	6.6
8	7.8	7.7	7.6	7.6
9	8.8	8.7	8.6	8.5
10	9.7	9.6	9.6	9.5
20	19.5	19.3	19.1	19.0
30	29.2	29.0	28.7	28.5
40	39.0	38.6	38.3	38.0
50	48.7	48.3	47.9	47.5

6	5.6	5.6	5.5	5.5
7	6.6	6.5	6.5	6.4
8	7.5	7.4	7.4	7.3
9	8.5	8.4	8.3	8.2
10	9.4	9.3	9.2	9.1
20	18.8	18.6	18.5	18.3
30	28.2	28.0	27.7	27.5
40	37.6	37.3	37.0	36.6
50	47.1	46.6	46.2	45.8

6	5.4	0.3	0.2
7	6.3	0.3	0.3
8	7.2	0.4	0.3
9	8.2	0.4	0.4
10	9.1	0.5	0.4
20	18.1	1.0	0.8
30	27.2	1.5	1.2
40	36.3	2.0	1.6
50	45.4	2.5	2.1

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS

13°

S. S.							P. P.				
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.					
0	9.35 209	54	9.36 336	57	0.63 663	9.98 872	60				
1	9.35 263	54	9.36 394	57	0.63 606	9.98 869	59				
2	9.35 318	54	9.36 451	57	0.63 548	9.98 866	58				
3	9.35 372	54	9.36 509	57	0.63 491	9.98 863	57	57	57	56	56
4	9.35 427	54	9.36 566	57	0.63 433	9.98 860	56	6	5.7	5.7	5.6
5	9.35 481	54	9.36 623	57	0.63 376	9.98 858	55	7	6.7	6.6	6.6
6	9.35 536	54	9.36 681	57	0.63 319	9.98 855	54	8	7.6	7.6	7.5
7	9.35 590	54	9.36 738	57	0.63 262	9.98 852	53	9	8.6	8.5	8.4
8	9.35 644	54	9.36 795	57	0.63 204	9.98 849	52	10	9.6	9.5	9.4
9	9.35 698	54	9.36 852	57	0.63 147	9.98 846	51	20	19.1	19.0	18.8
10	9.35 752	54	9.36 909	57	0.63 090	9.98 843	50	30	28.7	28.5	28.2
11	9.35 806	54	9.36 966	57	0.63 033	9.98 840	49	40	38.3	38.0	37.6
12	9.35 860	54	9.37 023	56	0.62 977	9.98 837	48	50	47.9	47.5	46.6
13	9.35 914	53	9.37 080	57	0.62 920	9.98 834	47				
14	9.35 968	54	9.37 136	56	0.62 863	9.98 831	46	53	53	54	54
15	9.36 021	53	9.37 193	57	0.62 806	9.98 828	45	6	5.5	5.5	5.4
16	9.36 075	53	9.37 250	56	0.62 750	9.98 825	44	7	6.5	6.4	6.3
17	9.36 128	53	9.37 306	56	0.62 693	9.98 822	43	8	7.4	7.3	7.2
18	9.36 182	53	9.37 363	56	0.62 637	9.98 819	42	9	8.3	8.2	8.1
19	9.36 235	53	9.37 419	56	0.62 580	9.98 816	41	10	9.2	9.1	9.0
20	9.36 289	53	9.37 475	56	0.62 524	9.98 813	40	20	18.5	18.3	18.1
21	9.36 342	53	9.37 532	56	0.62 468	9.98 810	39	30	27.7	27.5	27.0
22	9.36 395	53	9.37 588	56	0.62 412	9.98 807	38	40	37.0	36.6	36.0
23	9.36 448	53	9.37 644	56	0.62 356	9.98 804	37	50	46.2	45.8	45.0
24	9.36 501	53	9.37 700	56	0.62 299	9.98 801	36				
25	9.36 554	53	9.37 756	56	0.62 243	9.98 798	35	53	53	52	52
26	9.36 607	53	9.37 812	55	0.62 188	9.98 795	34	6	5.3	5.3	5.2
27	9.36 660	53	9.37 868	56	0.62 132	9.98 792	33	7	6.2	6.2	6.1
28	9.36 713	52	9.37 924	56	0.62 076	9.98 789	32	8	7.1	7.0	6.9
29	9.36 766	53	9.37 979	55	0.62 020	9.98 786	31	9	8.0	7.9	7.8
30	9.36 818	52	9.38 035	56	0.61 964	9.98 783	30	10	8.9	8.8	8.6
31	9.36 871	52	9.38 091	55	0.61 909	9.98 780	29	20	17.8	17.6	17.3
32	9.36 923	52	9.38 146	55	0.61 853	9.98 777	28	30	26.7	26.5	26.0
33	9.36 976	52	9.38 202	55	0.61 798	9.98 774	27	40	35.6	35.3	34.6
34	9.37 028	52	9.38 257	55	0.61 742	9.98 771	26	50	44.6	44.1	43.3
35	9.37 081	52	9.38 313	55	0.61 687	9.98 768	25				
36	9.37 133	52	9.38 368	55	0.61 632	9.98 765	24	51	51	50	50
37	9.37 185	52	9.38 423	55	0.61 576	9.98 762	23	6	5.1	5.1	5.0
38	9.37 237	52	9.38 478	55	0.61 521	9.98 759	22	7	6.0	5.9	5.9
39	9.37 289	52	9.38 533	55	0.61 466	9.98 755	21	8	6.8	6.8	6.7
40	9.37 341	52	9.38 589	55	0.61 411	9.98 752	20	9	7.7	7.6	7.6
41	9.37 393	51	9.38 644	54	0.61 356	9.98 749	19	10	8.6	8.5	8.4
42	9.37 445	52	9.38 698	55	0.61 301	9.98 746	18	20	17.1	17.0	16.8
43	9.37 497	51	9.38 753	55	0.61 246	9.98 743	17	30	25.7	25.5	25.2
44	9.37 548	52	9.38 808	54	0.61 191	9.98 740	16	40	34.3	34.0	33.6
45	9.37 600	51	9.38 863	55	0.61 137	9.98 737	15	50	42.9	42.5	42.1
46	9.37 652	51	9.38 918	54	0.61 082	9.98 734	14				
47	9.37 703	51	9.38 972	54	0.61 027	9.98 731	13	3	3	2	2
48	9.37 755	51	9.39 027	54	0.60 973	9.98 728	12	6	0.3	0.3	0.2
49	9.37 806	51	9.39 081	54	0.60 918	9.98 725	11	7	0.4	0.3	0.3
50	9.37 857	51	9.39 136	54	0.60 864	9.98 721	10	8	0.4	0.4	0.3
51	9.37 909	51	9.39 190	54	0.60 809	9.98 718	9	9	0.5	0.4	0.4
52	9.37 960	51	9.39 244	54	0.60 753	9.98 715	8	10	0.6	0.5	0.4
53	9.38 011	51	9.39 299	54	0.60 701	9.98 712	7	20	1.1	1.0	0.8
54	9.38 062	51	9.39 353	54	0.60 647	9.98 709	6	30	1.7	1.5	1.2
55	9.38 113	51	9.39 407	54	0.60 592	9.98 706	5	40	2.3	2.0	1.6
56	9.38 164	50	9.39 461	54	0.60 538	9.98 703	4	50	2.9	2.5	2.1
57	9.38 215	51	9.39 515	54	0.60 484	9.98 700	3				
58	9.38 266	51	9.39 569	54	0.60 430	9.98 696	2				
59	9.38 317	51	9.39 623	54	0.60 376	9.98 693	1				
60	9.38 367	50	9.39 677	53	0.60 323	9.98 690	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	'	P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

14°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.38 367	56	9.39 677	54	0.60 323	9.98 698	33	60	
1	9.38 418	50	9.39 731	53	0.60 269	9.98 689	33	59	
2	9.38 468	50	9.39 784	54	0.60 218	9.98 684	33	58	
3	9.38 519	50	9.39 838	53	0.60 167	9.98 681	33	57	
4	9.38 569	50	9.39 892	53	0.60 108	9.98 678	33	56	
5	9.38 620	50	9.39 945	53	0.60 054	9.98 674	33	55	
6	9.38 670	50	9.39 999	53	0.60 001	9.98 671	33	54	
7	9.38 720	50	9.40 052	53	0.59 949	9.98 668	33	53	
8	9.38 771	50	9.40 106	53	0.59 894	9.98 665	33	52	
9	9.38 821	50	9.40 159	53	0.59 841	9.98 662	33	51	
10	9.38 871	50	9.40 212	53	0.59 787	9.98 658	33	50	
11	9.38 921	50	9.40 265	53	0.59 734	9.98 655	33	49	
12	9.38 971	50	9.40 318	53	0.59 681	9.98 652	33	48	
13	9.39 021	50	9.40 372	53	0.59 628	9.98 649	33	47	
14	9.39 071	50	9.40 425	53	0.59 575	9.98 646	33	46	
15	9.39 126	49	9.40 478	53	0.59 522	9.98 642	33	45	
16	9.39 176	49	9.40 531	52	0.59 469	9.98 639	33	44	
17	9.39 220	49	9.40 583	53	0.59 416	9.98 636	33	43	
18	9.39 269	49	9.40 636	52	0.59 363	9.98 633	33	42	
19	9.39 319	49	9.40 689	52	0.59 311	9.98 630	33	41	
20	9.39 368	49	9.40 742	52	0.59 258	9.98 626	33	40	
21	9.39 418	49	9.40 794	52	0.59 205	9.98 623	33	39	
22	9.39 467	49	9.40 847	52	0.59 153	9.98 620	33	38	
23	9.39 516	49	9.40 899	52	0.59 100	9.98 617	33	37	
24	9.39 566	49	9.40 952	52	0.59 048	9.98 613	33	36	
25	9.39 615	49	9.41 004	52	0.58 995	9.98 610	33	35	
26	9.39 664	49	9.41 057	52	0.58 943	9.98 607	33	34	
27	9.39 713	49	9.41 109	52	0.58 891	9.98 604	33	33	
28	9.39 762	49	9.41 161	52	0.58 838	9.98 600	33	32	
29	9.39 811	49	9.41 213	52	0.58 786	9.98 597	33	31	
30	9.39 860	49	9.41 266	52	0.58 734	9.98 594	33	30	
31	9.39 909	48	9.41 318	52	0.58 682	9.98 591	33	29	
32	9.39 957	48	9.41 370	52	0.58 630	9.98 587	33	28	
33	9.40 006	48	9.41 422	52	0.58 578	9.98 584	33	27	
34	9.40 055	48	9.41 474	51	0.58 526	9.98 581	33	26	
35	9.40 103	48	9.41 525	52	0.58 474	9.98 578	33	25	
36	9.40 152	48	9.41 577	52	0.58 422	9.98 574	33	24	
37	9.40 200	48	9.41 629	51	0.58 370	9.98 571	33	23	
38	9.40 249	48	9.41 681	51	0.58 319	9.98 568	33	22	
39	9.40 297	48	9.41 732	51	0.58 267	9.98 564	33	21	
40	9.40 345	48	9.41 784	52	0.58 216	9.98 561	33	20	
41	9.40 394	48	9.41 836	51	0.58 164	9.98 558	33	19	
42	9.40 442	48	9.41 887	51	0.58 112	9.98 554	33	18	
43	9.40 490	48	9.41 938	51	0.58 061	9.98 551	33	17	
44	9.40 538	48	9.41 990	51	0.58 010	9.98 548	33	16	
45	9.40 586	48	9.42 041	51	0.57 958	9.98 544	33	15	
46	9.40 634	48	9.42 092	51	0.57 907	9.98 541	33	14	
47	9.40 682	48	9.42 144	51	0.57 856	9.98 538	33	13	
48	9.40 730	47		51	0.57 805	9.98 534	33	12	
49	9.40 777	47		51	0.57 753	9.98 531	33	11	
50	9.40 825	47		51	0.57 702	9.98 528	33	10	
51	9.40 873	47		51	0.57 651	9.98 524	33	9	
52	9.40 920	47	9.42 390	51	0.57 600	9.98 521	33	8	
53	9.40 968	47	9.42 450	50	0.57 549	9.98 518	33	7	
54	9.41 015	47	9.42 501	50	0.57 499	9.98 514	33	6	
55	9.41 063	47	9.42 552	51	0.57 448	9.98 511	33	5	
56	9.41 110	47	9.42 602	50	0.57 397	9.98 508	33	4	
57	9.41 158	47	9.42 653	51	0.57 346	9.98 504	33	3	
58	9.41 205	47	9.42 704	50	0.57 296	9.98 501	33	2	
59	9.41 253	47	9.42 754	50	0.57 245	9.98 498	33	1	
60	9.41 299	47	9.42 805	50	0.57 195	9.98 494	33	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

15°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.41 299	47	9.42 805	51	0.57 195	9.98 494	60		
1	9.41 346	47	9.42 856	50	0.57 144	9.98 491	59		
2	9.41 394	47	9.42 906	50	0.57 094	9.98 489	58		
3	9.41 441	47	9.42 956	50	0.57 043	9.98 484	57		50
4	9.41 488	47	9.43 007	50	0.56 993	9.98 481	56	6	5.0
5	9.41 534	46	9.43 057	50	0.56 942	9.98 477	55	7	5.8
6	9.41 581	47	9.43 107	50	0.56 892	9.98 474	54	8	6.6
7	9.41 628	47	9.43 157	50	0.56 842	9.98 470	53	9	7.5
8	9.41 675	46	9.43 208	50	0.56 792	9.98 467	52	10	8.3
9	9.41 721	46	9.43 258	50	0.56 742	9.98 464	51	20	16.6
10	9.41 768	47	9.43 308	50	0.56 692	9.98 460	50	30	25.0
11	9.41 815	46	9.43 358	50	0.56 642	9.98 457	49	40	33.3
12	9.41 861	46	9.43 408	50	0.56 592	9.98 453	48	50	41.6
13	9.41 908	46	9.43 458	50	0.56 542	9.98 450	47		
14	9.41 954	46	9.43 508	49	0.56 492	9.98 446	46		
15	9.42 000	46	9.43 557	50	0.56 442	9.98 443	45	49	48
16	9.42 047	46	9.43 607	49	0.56 392	9.98 439	44	6	4.8
17	9.42 093	46	9.43 657	49	0.56 343	9.98 436	43	7	5.6
18	9.42 139	46	9.43 706	50	0.56 293	9.98 433	42	8	6.4
19	9.42 185	46	9.43 756	49	0.56 243	9.98 429	41	9	7.2
20	9.42 232	46	9.43 806	49		9.98 426	40	10	8.0
21	9.42 278	46	9.43 855	49		9.98 422	39	20	16.0
22	9.42 324	46	9.43 905	49		9.98 419	38	30	24.0
23	9.42 369	46	9.43 954	49		9.98 415	37	40	32.0
24	9.42 415	46	9.44 003	49		9.98 412	36	50	40.0
25	9.42 461	46	9.44 053	49		9.98 408	35		
26	9.42 507	46	9.44 102	49		9.98 405	34	47	46
27	9.42 553	46	9.44 151	49		9.98 401	33	6	4.6
28	9.42 598	46	9.44 200	49		9.98 398	32	7	5.3
29	9.42 644	46	9.44 249	49		9.98 394	31	8	6.1
30	9.42 690	46	9.44 299	49		9.98 391	80	9	6.9
31	9.42 735	46	9.44 348	49		9.98 387	29	10	7.6
32	9.42 781	46	9.44 397	49		9.98 384	28	20	15.3
33	9.42 826	46	9.44 446	49		9.98 380	27	30	23.0
34	9.42 871	46	9.44 494	48		9.98 377	26	40	30.6
35	9.42 917	46	9.44 543	49		9.98 373	25	50	38.3
36	9.42 962	46	9.44 592	49		9.98 370	24		
37	9.43 007	46	9.44 641	49		9.98 366	23	45	44
38	9.43 052	46	9.44 690	48		9.98 363	22	6	4.4
39	9.43 098	46	9.44 738	48		9.98 359	21	7	5.1
40	9.43 143	46	9.44 787	48	0.55 213	9.98 356	20	8	5.8
41	9.43 188	46	9.44 835	48	0.55 161	9.98 352	19	9	6.6
42	9.43 233	46	9.44 884	48	0.55 116	9.98 348	18	10	7.3
43	9.43 278	46	9.44 932	48	0.55 069	9.98 345	17	20	14.6
44	9.43 322	46	9.44 981	48	0.55 019	9.98 341	16	30	22.0
45	9.43 367	46	9.45 029	48	0.54 970	9.98 338	15	40	29.3
46	9.43 412	46	9.45 077	48	0.54 922	9.98 334	14	50	36.6
47	9.43 457	46	9.45 126	48	0.54 874	9.98 331	13		
48	9.43 501	46	9.45 174	48	0.54 825	9.98 327	12		
49	9.43 546	46	9.45 222	48	0.54 777	9.98 324	11		
50	9.43 591	46	9.45 270	48	0.54 729	9.98 320	10	4	3
51	9.43 635	46	9.45 318	48	0.54 681	9.98 316	9	6	0.3
52	9.43 680	46	9.45 367	48	0.54 633	9.98 313	8	7	0.3
53	9.43 724	46	9.45 415	48	0.54 585	9.98 309	7	8	0.4
54	9.43 768	46	9.45 463	48	0.54 537	9.98 306	6	9	0.4
55	9.43 813	46	9.45 510	49	0.54 489	9.98 302	5	10	0.5
56	9.43 857	46	9.45 558	48	0.54 441	9.98 298	4	20	1.0
57	9.43 901	46	9.45 606	48	0.54 393	9.98 295	3	30	1.5
58	9.43 945	46	9.45 654	48	0.54 346	9.98 291	2	40	2.0
59	9.43 989	46	9.45 702	48	0.54 298	9.98 288	1	50	2.5
60	9.44 034	46	9.45 749	47	0.54 250	9.98 284	4		
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

16°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.44 034	44	9.45 746	48	0.54 250	9.98 284	3	60	
1	9.44 078	44	9.45 797	47	0.54 202	9.98 280	4	59	
2	9.44 122	44	9.45 845	47	0.54 155	9.98 277	4	58	
3	9.44 166	44	9.45 892	47	0.54 107	9.98 273	4	57	
4	9.44 209	43	9.45 940	47	0.54 060	9.98 269	4	56	
5	9.44 253	44	9.45 989	47	0.54 012	9.98 266	4	55	
6	9.44 297	43	9.46 035	47	0.53 965	9.98 262	4	54	
7	9.44 341	43	9.46 082	47	0.53 917	9.98 258	4	53	
8	9.44 384	43	9.46 129	47	0.53 870	9.98 255	4	52	
9	9.44 428	44	9.46 177	47	0.53 823	9.98 251	4	51	
10	9.44 472	43	9.46 224	47	0.53 776	9.98 247	4	50	
11	9.44 515	43	9.46 271	47	0.53 728	9.98 244	4	49	
12	9.44 559	43	9.46 318	47	0.53 681	9.98 240	4	48	
13	9.44 602	43	9.46 366	47	0.53 634	9.98 236	4	47	
14	9.44 646	43	9.46 413	47	0.53 587	9.98 233	4	46	
15	9.44 689	43	9.46 460	47	0.53 540	9.98 229	4	45	
16	9.44 732	43	9.46 507	47	0.53 493	9.98 225	4	44	
17	9.44 776	43	9.46 554	47	0.53 446	9.98 222	4	43	
18	9.44 819	43	9.46 601	47	0.53 399	9.98 218	4	42	
19	9.44 862	43	9.46 647	46	0.53 352	9.98 214	4	41	
20	9.44 905	43	9.46 694	47	0.53 305	9.98 211	3	40	
21	9.44 948	43	9.46 741	47	0.53 258	9.98 207	4	39	
22	9.44 991	43	9.46 788	46	0.53 212	9.98 203	4	38	
23	9.45 034	43	9.46 834	46	0.53 165	9.98 200	3	37	
24	9.45 077	43	9.46 881	47	0.53 118		4	36	
25	9.45 120	43	9.46 928	46	0.53 072		3	35	
26	9.45 163	42	9.46 974	46	0.53 025		4	34	
27	9.45 206	43	9.47 021	46	0.52 979		3	33	
28	9.45 249	43	9.47 067	46	0.52 932		4	32	
29	9.45 291	42	9.47 114	46	0.52 886	9.98 177	3	31	
30	9.45 334	42	9.47 160	46	0.52 839	9.98 173	4	30	
31	9.45 377	42	9.47 207	46	0.52 793	9.98 170	3	29	
32	9.45 419	42	9.47 253	46	0.52 747	9.98 166	4	28	
33	9.45 462	42	9.47 299	46	0.52 700	9.98 162	3	27	
34	9.45 504	42	9.47 345	46	0.52 654	9.98 158	4	26	
35	9.45 547	42	9.47 392	46	0.52 608	9.98 155	3	25	
36	9.45 589	42	9.47 438	46	0.52 562	9.98 151	4	24	
37	9.45 631	42	9.47 484	46	0.52 516	9.98 147	3	23	
38	9.45 674	42	9.47 530	46	0.52 469	9.98 143	4	22	
39	9.45 716	42	9.47 576	46	0.52 423	9.98 140	3	21	
40	9.45 758	42	9.47 622	46	0.52 377	9.98 136	4	20	
41	9.45 800	42	9.47 668	46	0.52 331	9.98 132	3	19	
42	9.45 842	42	9.47 714	45	0.52 286	9.98 128	4	18	
43	9.45 885	42	9.47 760	46	0.52 240	9.98 124	3	17	
44	9.45 927	42	9.47 806	46	0.52 194	9.98 121	4	16	
45	9.45 969	42	9.47 851	45	0.52 148	9.98 117	3	15	
46	9.46 011	42	9.47 897	46	0.52 102	9.98 113	4	14	
47	9.46 052	41	9.47 943	45	0.52 057	9.98 109	3	13	
48	9.46 094	42	9.47 989	46	0.52 011	9.98 105	4	12	
49	9.46 136	42	9.48 034	45	0.51 965	9.98 102	3	11	
50	9.46 178	41	9.48 080	45	0.51 920	9.98 098	4	10	
51	9.46 220	42	9.48 125	45	0.51 874	9.98 094	3	9	
52	9.46 261	41	9.48 171	45	0.51 829	9.98 090	4	8	
53	9.46 303	42	9.48 216	45	0.51 783	9.98 086	3	7	
54	9.46 345	41	9.48 262	45	0.51 738	9.98 082	4	6	
55	9.46 386	41	9.48 307	45	0.51 692	9.98 079	3	5	
56	9.46 428	41	9.48 353	45	0.51 647	9.98 075	4	4	
57	9.46 469	41	9.48 398	45	0.51 602	9.98 071	3	3	
58	9.46 511	41	9.48 443	45	0.51 556	9.98 067	4	2	
59	9.46 552	41	9.48 488	45	0.51 511	9.98 063	3	1	
60	9.46 593	41	9.48 534	45	0.51 466	9.98 059	4	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS

17°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.46 593	41	9.48 534	45	0.51 406	9.98 059	3	60	
1	9.46 635	41	9.48 579	45	0.51 421	9.98 056	3	59	
2	9.46 676	41	9.48 624	45	0.51 376	9.98 052	4	58	
3	9.46 717	41	9.48 669	45	0.51 330	9.98 048	4	57	45 45 44 44
4	9.46 758	41	9.48 714	45	0.51 285	9.98 044	4	56	6 4.3 4.5 4.4 4.4
5	9.46 799	41	9.48 759	45	0.51 240	9.98 040	3	55	7 5.3 5.2 5.2 5.1
6	9.46 840	41	9.48 804	45	0.51 195	9.98 036	4	54	8 6.0 6.0 5.9 5.8
7	9.46 881	41	9.48 849	44	0.51 151	9.98 032	4	53	9 6.8 6.7 6.7 6.6
8	9.46 922	41	9.48 894	45	0.51 106	9.98 028	4	52	10 7.6 7.5 7.4 7.3
9	9.46 963	41	9.48 939	45	0.51 061	9.98 024	4	51	20 15.1 15.0 14.8 14.6
10	9.47 004	41	9.48 984	45	0.51 016	9.98 021	3	50	30 22.7 22.5 22.2 22.0
11	9.47 045	41	9.49 028	44	0.50 971	9.98 017	4	49	40 30.3 30.0 29.6 29.3
12	9.47 086	41	9.49 073	45	0.50 926	9.98 013	4	48	50 37.9 37.5 37.1 36.6
13	9.47 127	40	9.49 118	44	0.50 882	9.98 009	4	47	
14	9.47 168	41	9.49 162	44	0.50 837	9.98 005	4	46	
15	9.47 208	40	9.49 207	45	0.50 792	9.98 001	4	45	43 43
16	9.47 249	40	9.49 252	44	0.50 748	9.97 997	3	44	6 4.3 4.3
17	9.47 290	41	9.49 296	44	0.50 703	9.97 993	4	43	7 5.1 5.0
18	9.47 330	40	9.49 341	44	0.50 659	9.97 989	4	42	8 5.8 5.7
19	9.47 371	40	9.49 385	44	0.50 614	9.97 985	4	41	9 6.5 6.4
20	9.47 411	40	9.49 430	44	0.50 570	9.97 981	4	40	10 7.2 7.1
21	9.47 452	40	9.49 474	44	0.50 525	9.97 977	4	39	20 14.5 14.3
22	9.47 492	40	9.49 518	44	0.50 481	9.97 973	4	38	30 21.7 21.5
23	9.47 532	40	9.49 563	44	0.50 437	9.97 969	4	37	40 29.0 28.6
24	9.47 573	40	9.49 607	44	0.50 392	9.97 966	3	36	50 36.2 35.8
25	9.47 613	40	9.49 651	44	0.50 348	9.97 962	4	35	
26	9.47 653	40	9.49 695	44	0.50 304	9.97 958	4	34	41 41 40 40
27	9.47 694	40	9.49 740	44	0.50 260	9.97 954	4	33	4.1 4.1 4.0 4.0
28	9.47 734	40	9.49 784	44	0.50 216	9.97 950	4	32	4.8 4.8 4.7 4.6
29	9.47 774	40	9.49 828	44	0.50 172	9.97 946	4	31	5.5 5.4 5.4 5.3
30	9.47 814	40	9.49 872	44	0.50 128	9.97 942	4	80	6.2 6.1 6.1 6.0
31	9.47 854	40	9.49 916	41	0.50 083	9.97 938	4	29	6.9 6.8 6.7 6.6
32	9.47 894	40	9.49 960	41	0.50 039	9.97 934	4	28	3.8 13.6 13.5 13.3
33	9.47 934	40	9.50 004	43	0.49 996	9.97 930	4	27	0.7 20.5 20.2 20.0
34	9.47 974	40	9.50 048	44	0.49 952	9.97 926	4	26	7.6 27.3 27.0 26.6
35	9.48 014	40	9.50 092	44	0.49 908	9.97 922	4	25	4.6 34.1 33.7 33.3
36	9.48 054	40	9.50 136	44	0.49 864	9.97 918	4	24	
37	9.48 093	39	9.50 179	43	0.49 820	9.97 914	4	23	39 39 38
38	9.48 133	40	9.50 223	44	0.49 776	9.97 910	4	22	6 3.9 3.9 3.8
39	9.48 173	39	9.50 267	43	0.49 731	9.97 906	4	21	7 4.6 4.5 4.5
40	9.48 213	40	9.50 311	44	0.49 687	9.97 902	4	20	8 5.2 5.2 5.1
41	9.48 252	39	9.50 354	43	0.49 643	9.97 898	4	19	9 5.9 5.8 5.8
42	9.48 292	39	9.50 398	43	0.49 602	9.97 894	4	18	10 6.6 6.5 6.4
43	9.48 331	39	9.50 442	44	0.49 558	9.97 890	4	17	20 13.1 13.0 12.8
44	9.48 371	39	9.50 485	43	0.49 514	9.97 886	4	16	30 19.7 19.5 19.2
45	9.48 410	39	9.50 529	43	0.49 471	9.97 881	4	15	40 26.3 26.0 25.6
46	9.48 450	39	9.50 572	43	0.49 427	9.97 877	4	14	50 32.9 32.5 32.1
47	9.48 489	39	9.50 616	43	0.49 384	9.97 873	4	13	
48	9.48 529	39	9.50 659	43	0.49 340	9.97 869	4	12	4 4 3
49	9.48 568	39	9.50 702	43	0.49 297	9.97 865	4	11	6 0.4 0.4 0.3
50	9.48 607	39	9.50 746	43	0.49 254	9.97 861	4	10	7 0.5 0.4 0.4
51	9.48 646	39	9.50 789	43	0.49 210	9.97 857	4	9	8 0.6 0.5 0.4
52	9.48 686	39	9.50 832	43	0.49 167	9.97 853	4	8	9 0.7 0.6 0.5
53	9.48 725	39	9.50 876	43	0.49 124	9.97 849	4	7	10 0.9 0.8 0.6
54	9.48 764	39	9.50 919	43	0.49 081	9.97 845	4	6	20 1.5 1.3 1.1
55	9.48 803	39	9.50 962	43	0.49 038	9.97 841	4	5	30 2.2 2.0 1.7
56	9.48 842	39	9.51 005	43	0.48 994	9.97 837	4	4	40 3.0 2.6 2.3
57	9.48 881	39	9.51 048	43	0.48 951	9.97 833	4	3	50 3.7 3.3 2.9
58	9.48 920	39	9.51 091	43	0.48 908	9.97 829	4	2	
59	9.48 959	39	9.51 134	43	0.48 865	9.97 824	4	1	
60	9.48 998	38	9.51 177	43	0.48 822	9.97 820	4	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

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E VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
18°

Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.			
9.48 998	39	9.51 177	43	0.48 822	9.97 820	4	60			
9.49 037	39	9.51 220	43	0.48 779	9.97 816	4	59			
9.49 076	38	9.51 263	43	0.48 736	9.97 812	4	58			
9.49 114	39	9.51 306	43	0.48 693	9.97 808	4	57	43	42	42
9.49 153	38	9.51 349	42	0.48 650	9.97 804	4	56	6	4.3	4.2
9.49 192	39	9.51 392	43	0.48 608	9.97 800	4	55	7	5.0	4.9
9.49 231	38	9.51 435	42	0.48 565	9.97 796	4	54	8	5.7	5.6
9.49 269	38	9.51 477	43	0.48 522	9.97 792	4	53	9	6.4	6.3
9.49 308	38	9.51 520	42	0.48 479	9.97 787	4	52	10	7.1	7.0
9.49 346	38	9.51 563	43	0.48 437	9.97 783	4	51	20	14.3	14.0
9.49 385	38	9.51 605	43	0.48 394	9.97 779	4	50	30	21.5	21.0
9.49 423	38	9.51 648	42	0.48 351	9.97 775	4	49	40	28.6	28.0
9.49 462	38	9.51 691	42	0.48 309	9.97 771	4	48	50	35.8	35.0
9.49 500	38	9.51 733	42	0.48 266	9.97 767	4	47			
9.49 539	38	9.51 776	42	0.48 224	9.97 763	4	46			
9.49 577	38	9.51 818	42	0.48 181	9.97 758	4	45	41	41	
9.49 615	38	9.51 861	42	0.48 139	9.97 754	4	44	6	4.1	4.1
9.49 653	38	9.51 903	42	0.48 096	9.97 750	4	43	7	4.8	4.8
9.49 692	38	9.51 946	42	0.48 054	9.97 746	4	42	8	5.5	5.4
9.49 730	38	9.51 988	42	0.48 012	9.97 742	4	41	9	6.2	6.1
9.49 768	38	9.52 030	42	0.47 969	9.97 737	4	40	10	6.9	6.8
9.49 806	38	9.52 073	42	0.47 927	9.97 733	4	39	20	13.8	13.6
9.49 844	38	9.52 115	43	0.47 885	9.97 729	4	38	30	20.7	20.5
9.49 882	38	9.52 157	42	0.47 842	9.97 725	4	37	40	27.6	27.3
9.49 920	38	9.52 199	42	0.47 800	9.97 721	4	36	50	34.6	34.1
9.49 958	38	9.52 241	42	0.47 758	9.97 716	4	35			
9.49 996	37	9.52 284	42	0.47 716	9.97 712	4	34	39	38	38
9.50 034	38	9.52 326	42	0.47 674	9.97 708	4	33	6	3.9	3.8
9.50 072	38	9.52 368	42	0.47 632	9.97 704	4	32	7	4.5	4.4
9.50 110	37	9.52 410	42	0.47 590	9.97 700	4	31	8	5.2	5.0
9.50 147	38	9.52 452	42	0.47 548	9.97 695	4	30	9	5.8	5.7
9.50 185	37	9.52 494	42	0.47 506	9.97 691	4	29	10	6.5	6.3
9.50 223	37	9.52 536	42	0.47 464	9.97 687	4	28	20	13.0	12.6
9.50 261	38	9.52 578	41	0.47 422	9.97 683	4	27	30	19.5	19.0
9.50 298	37	9.52 619	42	0.47 380	9.97 678	4	26	40	26.0	25.3
9.50 336	37	9.52 661	42	0.47 338	9.97 674	4	25	50	32.5	31.6
9.50 373	37	9.52 703	42	0.47 296	9.97 670	4	24			
9.50 411	37	9.52 745	42	0.47 255	9.97 666	4	23	37	37	36
9.50 448	37	9.52 787	41	0.47 213	9.97 661	4	22	6	3.7	3.6
9.50 486	37	9.52 828	41	0.47 171	9.97 657	4	21	7	4.4	4.2
9.50 523	37	9.52 870	42	0.47 130	9.97 653	4	20	8	5.0	4.8
9.50 561	37	9.52 912	41	0.47 088	9.97 649	4	19	9	5.6	5.5
9.50 598	37	9.52 953	41	0.47 046	9.97 644	4	18	10	6.2	6.1
9.50 635	37	9.52 995	41	0.47 005	9.97 640	4	17	20	12.5	12.1
9.50 672	37	9.53 036	41	0.46 963	9.97 636	4	16	30	18.7	18.2
9.50 710	37	9.53 078	41	0.46 922	9.97 632	4	15	40	25.0	24.3
9.50 747	37	9.53 119	41	0.46 880	9.97 627	4	14	50	31.2	30.4
9.50 784	37	9.53 161	41	0.46 839	9.97 623	4	13			
9.50 821	37	9.53 202	41	0.46 797	9.97 619	4	12			
9.50 858	37	9.53 244	41	0.46 756	9.97 614	4	11			
9.50 895	37	9.53 285	41	0.46 714	9.97 610	4	10	4	4	
9.50 932	37	9.53 326	41	0.46 673	9.97 606	4	9	6	0.4	0.4
9.50 969	37	9.53 368	41	0.46 632	9.97 601	4	8	7	0.5	0.4
9.51 006	37	9.53 409	41	0.46 591	9.97 597	4	7	8	0.6	0.5
9.51 043	37	9.53 450	41	0.46 549	9.97 593	4	6	9	0.7	0.6
9.51 080	37	9.53 491	41	0.46 508	9.97 588	4	5	10	0.7	0.6
9.51 117	36	9.53 533	41	0.46 467	9.97 584	4	4	20	1.5	1.3
9.51 154	37	9.53 574	41	0.46 426	9.97 580	4	3	30	2.2	2.0
9.51 190	36	9.53 615	41	0.46 385	9.97 575	4	2	40	3.0	2.6
9.51 227	37	9.53 656	41	0.46 344	9.97 571	4	1	50	3.7	3.3
9.51 264	36	9.53 697	41	0.46 303	9.97 567	4	0			
Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.	P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS

19°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.			
0	9.51 264	37	9.53 697	41	0.46 303	9.97 567	4	60			
1	9.51 301	36	9.53 738	41	0.46 262	9.97 562	4	59			
2	9.51 337	36	9.53 779	41	0.46 221	9.97 558	4	58			
3	9.51 374	36	9.53 820	41	0.46 180	9.97 554	4	57	41	48	40
4	9.51 410	36	9.53 861	41	0.46 139	9.97 549	4	56	6	4.1	4.0
5	9.51 447	36	9.53 902	41	0.46 098	9.97 545	4	55	7	4.8	4.7
6	9.51 483	36	9.53 943	40	0.46 057	9.97 541	4	54	8	5.4	5.3
7	9.51 520	36	9.53 983	41	0.46 016	9.97 536	4	53	9	6.1	6.0
8	9.51 556	36	9.54 024	41	0.45 975	9.97 532	4	52	10	6.8	6.7
9	9.51 593	36	9.54 065	40	0.45 934	9.97 527	4	51	20	13.6	13.5
10	9.51 629	36	9.54 106	41	0.45 894	9.97 523	4	50	30	20.5	20.2
11	9.51 665	36	9.54 147	40	0.45 853	9.97 519	4	49	40	27.3	27.0
12	9.51 702	36	9.54 187	40	0.45 812	9.97 514	4	48	50	34.1	33.7
13	9.51 738	36	9.54 228	41	0.45 772	9.97 510	4	47			
14	9.51 774	36	9.54 269	40	0.45 731	9.97 505	4	46			
15	9.51 810	36	9.54 309	40	0.45 690	9.97 501	4	45	39	39	
16	9.51 847	36	9.54 350	40	0.45 650	9.97 497	4	44	6	3.9	3.9
17	9.51 883	36	9.54 390	40	0.45 609	9.97 492	4	43	7	4.6	4.5
18	9.51 919	36	9.54 431	40	0.45 569	9.97 488	4	42	8	5.2	5.2
19	9.51 955	36	9.54 471	40	0.45 528	9.97 483	4	41	9	5.9	5.8
20	9.51 991	36	9.54 512	40	0.45 488	9.97 479	4	40	10	6.6	6.5
21	9.52 027	36	9.54 552	40	0.45 447	9.97 475	4	39	20	13.1	13.0
22	9.52 063	36	9.54 593	40	0.45 407	9.97 470	4	38	30	19.7	19.5
23	9.52 099	36	9.54 633	40	0.45 367	9.97 466	4	37	40	26.3	26.0
24	9.52 135	35	9.54 673	40	0.45 326	9.97 461	4	36	50	32.9	32.5
25	9.52 170	35	9.54 714	40	0.45 286	9.97 457	4	35			
26	9.52 206	36	9.54 754	40	0.45 246	9.97 452	4	34	37	36	36
27	9.52 242	35	9.54 794	40	0.45 205	9.97 448	4	33	6	3.7	3.6
28	9.52 278	36	9.54 834	40	0.45 165	9.97 443	4	32	7	4.3	4.2
29	9.52 314	35	9.54 874	40	0.45 125	9.97 439	4	31	8	4.9	4.8
30	9.52 349	35	9.54 915	40	0.45 085	9.97 434	4	30	9	5.5	5.4
31	9.52 385	36	9.54 955	40	0.45 045	9.97 430	4	29	10	6.1	6.0
32	9.52 421	35	9.54 995	40	0.45 005	9.97 425	4	28	20	12.3	12.1
33	9.52 456	35	9.55 035	40	0.44 965	9.97 421	4	27	30	18.5	18.2
34	9.52 492	35	9.55 075	40	0.44 925	9.97 416	4	26	40	24.6	24.3
35	9.52 527	35	9.55 115	39	0.44 884	9.97 412	4	25	50	30.8	30.4
36	9.52 563	35	9.55 155	40	0.44 845	9.97 407	4	24			
37	9.52 598	35	9.55 195	40	0.44 805	9.97 403	4	23	35	35	34
38	9.52 634	35	9.55 235	40	0.44 765	9.97 398	4	22	6	3.5	3.4
39	9.52 669	35	9.55 275	40	0.44 725	9.97 394	4	21	7	4.1	4.0
40	9.52 704	35	9.55 315	40	0.44 685	9.97 389	4	20	8	4.7	4.6
41	9.52 740	35	9.55 355	39	0.44 645	9.97 385	4	19	9	5.3	5.2
42	9.52 775	35	9.55 394	40	0.44 605	9.97 380	4	18	10	5.9	5.7
43	9.52 810	35	9.55 434	39	0.44 565	9.97 376	4	17	20	11.8	11.5
44	9.52 846	35	9.55 474	40	0.44 526	9.97 371	4	16	30	17.7	17.2
45	9.52 881	35	9.55 514	39	0.44 486	9.97 367	4	15	40	23.6	23.0
46	9.52 916	35	9.55 553	40	0.44 446	9.97 362	4	14	50	29.6	28.7
47	9.52 951	35	9.55 593	39	0.44 406	9.97 358	4	13			
48	9.52 986	35	9.55 633	39	0.44 367	9.97 353	4	12			
49	9.53 021	35	9.55 672	39	0.44 327	9.97 349	4	11	5	4	4
50	9.53 056	35	9.55 712	39	0.44 288	9.97 344	4	10	6	0.5	0.4
51	9.53 091	35	9.55 751	40	0.44 248	9.97 340	5	9	7	0.6	0.5
52	9.53 126	35	9.55 791	39	0.44 208	9.97 335	4	8	8	0.6	0.5
53	9.53 161	35	9.55 831	39	0.44 169	9.97 330	4	7	9	0.7	0.6
54	9.53 196	35	9.55 870	39	0.44 129	9.97 326	4	6	10	0.8	0.6
55	9.53 231	34	9.55 909	39	0.44 090	9.97 321	4	5	20	1.6	1.3
56	9.53 266	35	9.55 949	39	0.44 051	9.97 317	4	4	30	2.5	2.0
57	9.53 301	35	9.55 988	39	0.44 011	9.97 312	4	3	40	3.3	2.6
58	9.53 335	34	9.56 028	39	0.43 972	9.97 308	4	2	50	4.1	3.3
59	9.53 370	35	9.56 067	39	0.43 932	9.97 303	5	1			
60	9.53 405	34	9.56 106	39	0.43 893	9.97 298	4	0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.				P. P.

70°

: VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
20°

Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.																																						
9.53 405	35	9.56 106	39	0.43 893	9.97 298	4	<div>3939</div> <table><tr><td>6</td><td>3.9</td><td>3.9</td></tr><tr><td>7</td><td>4.6</td><td>4.5</td></tr><tr><td>8</td><td>5.2</td><td>5.2</td></tr><tr><td>9</td><td>5.9</td><td>5.8</td></tr><tr><td>10</td><td>6.6</td><td>6.5</td></tr><tr><td>20</td><td>13.1</td><td>13.0</td></tr><tr><td>30</td><td>19.7</td><td>19.5</td></tr><tr><td>40</td><td>26.3</td><td>26.0</td></tr><tr><td>50</td><td>32.9</td><td>32.5</td></tr></table>			6	3.9	3.9	7	4.6	4.5	8	5.2	5.2	9	5.9	5.8	10	6.6	6.5	20	13.1	13.0	30	19.7	19.5	40	26.3	26.0	50	32.9	32.5									
6	3.9	3.9																																											
7	4.6	4.5																																											
8	5.2	5.2																																											
9	5.9	5.8																																											
10	6.6	6.5																																											
20	13.1	13.0																																											
30	19.7	19.5																																											
40	26.3	26.0																																											
50	32.9	32.5																																											
9.53 440	34	9.56 146	39	0.43 854	9.97 294	4																																							
9.53 474	34	9.56 185	39	0.43 815	9.97 289	4																																							
9.53 509	35	9.56 224	39	0.43 775	9.97 285	5																																							
9.53 544	34	9.56 263	39	0.43 736	9.97 280	4																																							
9.53 578	34	9.56 303	39	0.43 697	9.97 275	4																																							
9.53 613	34	9.56 342	39	0.43 658	9.97 271	4																																							
9.53 647	34	9.56 381	39	0.43 619	9.97 266	4																																							
9.53 682	34	9.56 420	39	0.43 580	9.97 261	5																																							
9.53 716	34	9.56 459	39	0.43 540	9.97 257	4																																							
9.53 750	34	9.56 498	39	0.43 501	9.97 252	4																																							
9.53 785	34	9.56 537	39	0.43 462	9.97 248	5	<div>383837</div> <table><tr><td>6</td><td>3.8</td><td>3.8</td><td>3.7</td></tr><tr><td>7</td><td>4.5</td><td>4.4</td><td>4.4</td></tr><tr><td>8</td><td>5.1</td><td>5.0</td><td>5.0</td></tr><tr><td>9</td><td>5.8</td><td>5.7</td><td>5.6</td></tr><tr><td>10</td><td>6.4</td><td>6.3</td><td>6.2</td></tr><tr><td>20</td><td>12.8</td><td>12.6</td><td>12.5</td></tr><tr><td>30</td><td>19.2</td><td>19.0</td><td>18.7</td></tr><tr><td>40</td><td>25.6</td><td>25.3</td><td>25.0</td></tr><tr><td>50</td><td>32.1</td><td>31.6</td><td>31.2</td></tr></table>			6	3.8	3.8	3.7	7	4.5	4.4	4.4	8	5.1	5.0	5.0	9	5.8	5.7	5.6	10	6.4	6.3	6.2	20	12.8	12.6	12.5	30	19.2	19.0	18.7	40	25.6	25.3	25.0	50	32.1	31.6	31.2
6	3.8	3.8	3.7																																										
7	4.5	4.4	4.4																																										
8	5.1	5.0	5.0																																										
9	5.8	5.7	5.6																																										
10	6.4	6.3	6.2																																										
20	12.8	12.6	12.5																																										
30	19.2	19.0	18.7																																										
40	25.6	25.3	25.0																																										
50	32.1	31.6	31.2																																										
9.53 819	34	9.56 576	39	0.43 423	9.97 243	4																																							
9.53 854	34	9.56 615	39	0.43 384	9.97 238	5																																							
9.53 888	34	9.56 654	38	0.43 346	9.97 234	4																																							
9.53 922	34	9.56 693	39	0.43 307	9.97 229	5																																							
9.53 956	34	9.56 732	39	0.43 268	9.97 224	4																																							
9.53 990	34	9.56 771	39	0.43 229	9.97 220	5																																							
9.54 025	34	9.56 810	39	0.43 190	9.97 215	4																																							
9.54 059	34	9.56 848	38	0.43 151	9.97 210	4																																							
9.54 093	34	9.56 887	39	0.43 112	9.97 206	4																																							
9.54 127	34	9.56 926	38	0.43 074	9.97 201	5																																							
9.54 161	34	9.56 965	39	0.43 035	9.97 196	4	<div>353434</div> <table><tr><td>6</td><td>3.5</td><td>3.4</td><td>3.4</td></tr><tr><td>7</td><td>4.1</td><td>4.0</td><td>3.9</td></tr><tr><td>8</td><td>4.6</td><td>4.6</td><td>4.5</td></tr><tr><td>9</td><td>5.2</td><td>5.2</td><td>5.1</td></tr><tr><td>10</td><td>5.8</td><td>5.7</td><td>5.6</td></tr><tr><td>20</td><td>11.6</td><td>11.5</td><td>11.3</td></tr><tr><td>30</td><td>17.5</td><td>17.2</td><td>17.0</td></tr><tr><td>40</td><td>23.3</td><td>23.0</td><td>22.6</td></tr><tr><td>50</td><td>29.1</td><td>28.7</td><td>28.3</td></tr></table>			6	3.5	3.4	3.4	7	4.1	4.0	3.9	8	4.6	4.6	4.5	9	5.2	5.2	5.1	10	5.8	5.7	5.6	20	11.6	11.5	11.3	30	17.5	17.2	17.0	40	23.3	23.0	22.6	50	29.1	28.7	28.3
6	3.5	3.4	3.4																																										
7	4.1	4.0	3.9																																										
8	4.6	4.6	4.5																																										
9	5.2	5.2	5.1																																										
10	5.8	5.7	5.6																																										
20	11.6	11.5	11.3																																										
30	17.5	17.2	17.0																																										
40	23.3	23.0	22.6																																										
50	29.1	28.7	28.3																																										
9.54 195	34	9.57 003	38	0.42 996	9.97 191	5																																							
9.54 229	34	9.57 042	38	0.42 958	9.97 187	4																																							
9.54 263	33	9.57 081	39	0.42 919	9.97 182	4																																							
9.54 297	34	9.57 119	38	0.42 880	9.97 177	5																																							
9.54 331	34	9.57 158	38	0.42 842	9.97 173	4																																							
9.54 365	34	9.57 196	38	0.42 803	9.97 168	5																																							
9.54 398	33	9.57 235	38	0.42 765	9.97 163	4																																							
9.54 432	34	9.57 274	39	0.42 726	9.97 159	4																																							
9.54 466	34	9.57 312	38	0.42 687	9.97 154	5																																							
9.54 500	33	9.57 350	38	0.42 649	9.97 149	4																																							
9.54 534	34	9.57 389	38	0.42 611	9.97 144	5																																							
9.54 567	33	9.57 427	38	0.42 572	9.97 140	4	<div>3333</div> <table><tr><td>6</td><td>3.3</td><td>3.3</td></tr><tr><td>7</td><td>3.9</td><td>3.8</td></tr><tr><td>8</td><td>4.4</td><td>4.4</td></tr><tr><td>9</td><td>5.0</td><td>4.9</td></tr><tr><td>10</td><td>5.6</td><td>5.5</td></tr><tr><td>20</td><td>11.1</td><td>11.0</td></tr><tr><td>30</td><td>16.7</td><td>16.5</td></tr><tr><td>40</td><td>22.3</td><td>22.0</td></tr><tr><td>50</td><td>27.9</td><td>27.5</td></tr></table>			6	3.3	3.3	7	3.9	3.8	8	4.4	4.4	9	5.0	4.9	10	5.6	5.5	20	11.1	11.0	30	16.7	16.5	40	22.3	22.0	50	27.9	27.5									
6	3.3	3.3																																											
7	3.9	3.8																																											
8	4.4	4.4																																											
9	5.0	4.9																																											
10	5.6	5.5																																											
20	11.1	11.0																																											
30	16.7	16.5																																											
40	22.3	22.0																																											
50	27.9	27.5																																											
9.54 601	33	9.57 466	38	0.42 534	9.97 135	5																																							
9.54 634	33	9.57 504	38	0.42 495	9.97 130	4																																							
9.54 668	34	9.57 542	38	0.42 457	9.97 125	5																																							
9.54 702	33	9.57 581	38	0.42 419	9.97 121	4																																							
9.54 735	33	9.57 619	38	0.42 380	9.97 116	5																																							
9.54 769	33	9.57 657	38	0.42 342	9.97 111	4	<div>54</div> <table><tr><td>6</td><td>0.5</td><td>0.4</td></tr><tr><td>7</td><td>0.6</td><td>0.5</td></tr><tr><td>8</td><td>0.6</td><td>0.6</td></tr><tr><td>9</td><td>0.7</td><td>0.7</td></tr><tr><td>10</td><td>0.8</td><td>0.7</td></tr><tr><td>20</td><td>1.6</td><td>1.5</td></tr><tr><td>30</td><td>2.5</td><td>2.2</td></tr><tr><td>40</td><td>3.3</td><td>3.0</td></tr><tr><td>50</td><td>4.1</td><td>3.7</td></tr></table>			6	0.5	0.4	7	0.6	0.5	8	0.6	0.6	9	0.7	0.7	10	0.8	0.7	20	1.6	1.5	30	2.5	2.2	40	3.3	3.0	50	4.1	3.7									
6	0.5	0.4																																											
7	0.6	0.5																																											
8	0.6	0.6																																											
9	0.7	0.7																																											
10	0.8	0.7																																											
20	1.6	1.5																																											
30	2.5	2.2																																											
40	3.3	3.0																																											
50	4.1	3.7																																											
9.54 802	33	9.57 696	38	0.42 304	9.97 106	5																																							
9.54 836	33	9.57 734	38	0.42 266	9.97 102	4																																							
9.54 869	33	9.57 772	38	0.42 227	9.97 097	5																																							
9.54 902	33	9.57 810	38	0.42 189	9.97 092	5																																							
9.54 936	33	9.57 848	38	0.42 151	9.97 087	4																																							
9.54 969	33	9.57 886	38	0.42 113	9.97 082	5																																							
9.55 002	33	9.57 925	38	0.42 075	9.97 078	4																																							
9.55 036	33	9.57 963	38	0.42 037	9.97 073	5																																							
9.55 069	33	9.58 001	38	0.41 999	9.97 068	4																																							
9.55 102	33	9.58 039	38	0.41 961	9.97 063	5																																							
9.55 135	33	9.58 077	38	0.41 923	9.97 058	5																																							
9.55 168	33	9.58 115	38	0.41 885	9.97 054	4																																							
9.55 202	33	9.58 153	38	0.41 847	9.97 049	5																																							
9.55 235	33	9.58 190	37	0.41 809	9.97 044	5																																							
9.55 268	33	9.58 228	38	0.41 771	9.97 039	4																																							
9.55 301	33	9.58 266	38	0.41 733	9.97 034	5																																							
9.55 334	33	9.58 304	38	0.41 695	9.97 029	5																																							
9.55 367	33	9.58 342	37	0.41 658	9.97 025	4																																							
9.55 400	33	9.58 380	38	0.41 620	9.97 020	5																																							
9.55 433	33	9.58 417	37	0.41 582	9.97 015	5	P. P.																																						
Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.																																							

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

21°

S. S.							P. P.					
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.					
0	9.55 433		9.58 417		0.41 582	9.97 015	4	60				
1	9.55 466	33	9.58 455	38	0.41 544	9.97 010	5	59				
2	9.55 498	32	9.58 493	37	0.41 507	9.97 005	5	58				
3	9.55 531	33	9.58 531	38	0.41 469	9.97 000	5	57	38	37	37	
4	9.55 564	33	9.58 568	37	0.41 431	9.96 995	5	56	6	3.8	3.7	3.7
		32		37			4		7	4.4	4.4	4.3
5	9.55 597	33	9.58 606	38	0.41 394	9.96 991	5	55	8	5.0	5.0	4.9
6	9.55 630	32	9.58 644	37	0.41 356	9.96 986	5	54	9	5.7	5.6	5.5
7	9.55 662	33	9.58 681	37	0.41 318	9.96 981	5	53	10	6.3	6.2	6.1
8	9.55 695	32	9.58 719	37	0.41 281	9.96 976	5	52	20	12.6	12.5	12.3
9	9.55 728	32	9.58 756	37	0.41 243	9.96 971	4	51	30	19.0	18.7	18.5
		32		37			5		40	25.3	25.0	24.6
10	9.55 760	32	9.58 794	37	0.41 206	9.96 966	5	50	50	31.6	31.2	30.8
11	9.55 793	32	9.58 831	37	0.41 168	9.96 961	5	49				
12	9.55 826	33	9.58 869	37	0.41 131	9.96 956	5	48				
13	9.55 858	32	9.58 906	37	0.41 093	9.96 952	4	47				
14	9.55 891	32	9.58 944	37	0.41 056	9.96 947	5	46				
		32		37			5		36	36		
15	9.55 923	32	9.58 981	37	0.41 018	9.96 942	5	45	6	3.6	3.6	
16	9.55 956	32	9.59 019	37	0.40 981	9.96 937	5	44	7	4.2	4.2	
17	9.55 988	32	9.59 056	37	0.40 944	9.96 932	5	43	8	4.8	4.8	
18	9.56 020	32	9.59 093	37	0.40 906	9.96 927	5	42	9	5.5	5.4	
19	9.56 053	32	9.59 131	37	0.40 869	9.96 922	4	41	10	6.1	6.0	
		32		37			5		20	12.1	12.0	
20	9.56 085	32	9.59 168	37	0.40 832	9.96 917	5	40	30	18.2	18.0	
21	9.56 118	32	9.59 205	37	0.40 794	9.96 912	5	39	40	24.3	24.0	
22	9.56 150	32	9.59 242	37	0.40 757	9.96 907	5	38	50	30.4	30.0	
23	9.56 182	32	9.59 280	37	0.40 720	9.96 902	5	37				
24	9.56 214	32	9.59 317	37	0.40 683	9.96 897	5	36				
		32		37			5					
25	9.56 247	32	9.59 354	37	0.40 646	9.96 892	5	35				
26	9.56 279	32	9.59 391	37	0.40 608	9.96 887	5	34	33	32	32	
27	9.56 311	32	9.59 428	37	0.40 571	9.96 882	5	33	6	3.3	3.2	3.2
28	9.56 343	32	9.59 465	37	0.40 534	9.96 877	5	32	7	3.8	3.8	3.7
29	9.56 375	32	9.59 502	37	0.40 497	9.96 873	4	31	8	4.4	4.3	4.2
		32		37			5		9	4.9	4.9	4.8
30	9.56 407	32	9.59 540	37	0.40 460	9.96 868	5	80	10	5.5	5.4	5.3
31	9.56 439	32	9.59 577	37	0.40 423	9.96 863	5	29	20	11.0	10.8	10.6
32	9.56 471	32	9.59 614	37	0.40 386	9.96 858	5	28	30	16.5	16.2	16.0
33	9.56 503	32	9.59 651	37	0.40 349	9.96 853	5	27	40	22.0	21.6	21.3
34	9.56 535	32	9.59 688	37	0.40 312	9.96 848	5	26	50	27.5	27.1	26.6
		32		36			5					
35	9.56 567	32	9.59 724	36	0.40 275	9.96 843	5	25				
36	9.56 599	32	9.59 761	37	0.40 238	9.96 838	5	24				
37	9.56 631	32	9.59 798	37	0.40 201	9.96 833	5	23				
38	9.56 663	31	9.59 835	37	0.40 164	9.96 828	5	22	31	31		
39	9.56 695	32	9.59 872	36	0.40 128	9.96 823	5	21	6	3.1	3.1	
		32		37			5		7	3.7	3.6	
40	9.56 727	31	9.59 909	37	0.40 091	9.96 818	5	20	8	4.2	4.1	
41	9.56 758	31	9.59 946	37	0.40 054	9.96 813	5	19	9	4.7	4.6	
42	9.56 790	32	9.59 982	36	0.40 017	9.96 808	5	18	10	5.2	5.1	
43	9.56 822	31	9.60 019	37	0.39 980	9.96 802	5	17	20	10.5	10.3	
44	9.56 854	32	9.60 056	36	0.39 944	9.96 797	5	16	30	15.7	15.5	
		31		37			5		40	21.0	20.6	
45	9.56 885	31	9.60 093	37	0.39 907	9.96 792	5	15	50	26.2	25.8	
46	9.56 917	31	9.60 129	36	0.39 870	9.96 787	5	14				
47	9.56 949	32	9.60 166	37	0.39 833	9.96 782	5	13				
48	9.56 980	31	9.60 203	36	0.39 797	9.96 777	5	12				
49	9.57 012	31	9.60 239	36	0.39 760	9.96 772	5	11				
		31		36			5		5	5	4	
50	9.57 043	31	9.60 276	36	0.39 724	9.96 767	5	10	6	0.5	0.5	0.4
51	9.57 075	31	9.60 312	36	0.39 687	9.96 762	5	9	7	0.6	0.6	0.5
52	9.57 106	31	9.60 349	37	0.39 650	9.96 757	5	8	8	0.7	0.6	0.6
53	9.57 138	31	9.60 386	36	0.39 614	9.96 752	5	7	9	0.8	0.7	0.7
54	9.57 169	31	9.60 422	36	0.39 577	9.96 747	5	6	10	0.9	0.8	0.7
		31		36			5		20	1.8	1.6	1.5
55	9.57 201	31	9.60 459	36	0.39 541	9.96 742	5	5	30	2.7	2.5	2.2
56	9.57 232	31	9.60 495	36	0.39 504	9.96 737	5	4	40	3.6	3.3	3.0
57	9.57 263	31	9.60 531	36	0.39 468	9.96 732	5	3	50	4.6	4.1	3.7
58	9.57 295	31	9.60 568	36	0.39 432	9.96 727	5	2				
59	9.57 326	31	9.60 604	36	0.39 395	9.96 721	5	1				
60	9.57 357	31	9.60 641	36	0.39 359	9.96 716	5	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

22°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.		
0	9.57 357	31	9.60 641	36	0.39 359	9.96 716	5	60		
1	9.57 389	31	9.60 677	36	0.39 322	9.96 711	5	59		
2	9.57 420	31	9.60 713	36	0.39 286	9.96 706	5	58		
3	9.57 451	31	9.60 750	36	0.39 250	9.96 701	5	57	36	36
4	9.57 482	31	9.60 786	36	0.39 213	9.96 696	5	56	6	3.6
5	9.57 513	31	9.60 822	36	0.39 177	9.96 691	5	55	7	4.2
6	9.57 544	31	9.60 859	36	0.39 141	9.96 686	5	54	8	4.8
7	9.57 576	31	9.60 895	36	0.39 105	9.96 681	5	53	9	5.4
8	9.57 607	31	9.60 931	36	0.39 069	9.96 675	5	52	10	6.0
9	9.57 638	31	9.60 967	36	0.39 032	9.96 670	5	51	20	12.0
10	9.57 669	31	9.61 003	36	0.38 996	9.96 665	5	50	30	18.0
11	9.57 700	31	9.61 039	36	0.38 960	9.96 660	5	49	40	24.0
12	9.57 731	31	9.61 076	36	0.38 924	9.96 655	5	48	50	30.0
13	9.57 762	30	9.61 112	36	0.38 888	9.96 650	5	47		
14	9.57 792	31	9.61 148	36	0.38 852	9.96 644	5	46		
15	9.57 823	31	9.61 184	36	0.38 816	9.96 639	5	45	35	35
16	9.57 854	31	9.61 220	36	0.38 780	9.96 634	5	44	6	3.5
17	9.57 885	30	9.61 256	36	0.38 744	9.96 629	5	43	7	4.1
18	9.57 916	31	9.61 292	36	0.38 708	9.96 624	5	42	8	4.6
19	9.57 947	30	9.61 328	36	0.38 672	9.96 619	5	41	9	5.2
20	9.57 977	31	9.61 364	36	0.38 636	9.96 613	5	40	10	5.8
21	9.58 008	30	9.61 400	36	0.38 600	9.96 608	5	39	20	11.6
22	9.58 039	31	9.61 436	36	0.38 564	9.96 603	5	38	30	17.5
23	9.58 070	30	9.61 472	35	0.38 528	9.96 598	5	37	40	23.3
24	9.58 100	30	9.61 507	36	0.38 492	9.96 593	5	36	50	29.1
25	9.58 131	31	9.61 543	36	0.38 456	9.96 587	5	35		
26	9.58 162	30	9.61 579	35	0.38 420	9.96 582	5	34	31	31
27	9.58 192	30	9.61 615	36	0.38 385	9.96 577	5	33	6	3.1
28	9.58 223	30	9.61 651	35	0.38 349	9.96 572	5	32	7	3.6
29	9.58 253	30	9.61 686	36	0.38 313	9.96 567	5	31	8	4.1
30	9.58 284	30	9.61 722	35	0.38 277	9.96 561	5	30	9	4.6
31	9.58 314	30	9.61 758	36	0.38 242	9.96 556	5	29	10	5.1
32	9.58 345	30	9.61 794	35	0.38 206	9.96 551	5	28	20	10.3
33	9.58 375	30	9.61 829	35	0.38 170	9.96 546	5	27	30	15.5
34	9.58 406	30	9.61 865	36	0.38 135	9.96 540	5	26	40	20.6
35	9.58 436	30	9.61 901	35	0.38 099	9.96 535	5	25	50	25.8
36	9.58 466	30	9.61 936	35	0.38 063	9.96 530	5	24		
37	9.58 497	30	9.61 972	35	0.38 028	9.96 525	5	23	36	30
38	9.58 527	30	9.62 007	35	0.37 992	9.96 519	5	22	6	2.9

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

23°

Log. Sin.							P. P.						
	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.						
0	9.59 188	29	9.62 785	35	0.37 215	9.96 402	59						
1	9.59 217	30	9.62 820	35	0.37 179	9.96 397	58						
2	9.59 247	29	9.62 855	35	0.37 144	9.96 392	57						
3	9.59 277	29	9.62 890	35	0.37 109	9.96 386	56						
4	9.59 306	30	9.62 925	35	0.37 074	9.96 381	55						
5	9.59 336	29	9.62 960	35	0.37 039	9.96 375	54						
6	9.59 366	29	9.62 995	35	0.37 004	9.96 370	53						
7	9.59 395	29	9.63 030	35	0.36 969	9.96 365	52						
8	9.59 425	29	9.63 065	35	0.36 934	9.96 359	51						
9	9.59 454	29	9.63 100	35	0.36 899	9.96 354	50						
10	9.59 484	29	9.63 135	35	0.36 864	9.96 349	49						
11	9.59 513	29	9.63 170	35	0.36 829	9.96 343	48						
12	9.59 543	29	9.63 205	34	0.36 794	9.96 338	47						
13	9.59 572	29	9.63 240	35	0.36 760	9.96 332	46						
14	9.59 602	29	9.63 275	35	0.36 725	9.96 327	45						
15	9.59 631	29	9.63 310	34	0.36 690	9.96 321	44						
16	9.59 661	29	9.63 344	35	0.36 655	9.96 316	43						
17	9.59 690	29	9.63 379	35	0.36 620	9.96 311	42						
18	9.59 719	29	9.63 414	34	0.36 585	9.96 305	41						
19	9.59 749	29	9.63 449	35	0.36 551	9.96 300	40						
20	9.59 778	29	9.63 484	34	0.36 516	9.96 294	39						
21	9.59 807	29	9.63 518	34	0.36 481	9.96 289	38						
22	9.59 837	29	9.63 553	35	0.36 447	9.96 283	37						
23	9.59 866	29	9.63 588	34	0.36 412	9.96 278	36						
24	9.59 895	29	9.63 622	34	0.36 377	9.96 272	35						
25	9.59 924	29	9.63 657	35	0.36 343	9.96 267	34						
26	9.59 953	29	9.63 692	34	0.36 308	9.96 261	33						
27	9.59 982	29	9.63 726	34	0.36 273	9.96 256	32						
28	9.60 012	29	9.63 761	34	0.36 239	9.96 251	31						
29	9.60 041	29	9.63 795	34	0.36 204	9.96 245	80						
30	9.60 070	29	9.63 830	34	0.36 170	9.96 240	29						
31	9.60 099	29	9.63 864	34	0.36 135	9.96 234	28						
32	9.60 128	29	9.63 899	34	0.36 101	9.96 229	27						
33	9.60 157	29	9.63 933	34	0.36 066	9.96 223	26						
34	9.60 186	29	9.63 968	34	0.36 032	9.96 218	25						
35	9.60 215	29	9.64 002	34	0.35 997	9.96 212	24						
36	9.60 244	29	9.64 037	34	0.35 963	9.96 206	23						
37	9.60 273	28	9.64 071	34	0.35 928	9.96 201	22						
38	9.60 301	29	9.64 106	34	0.35 894	9.96 195	21						
39	9.60 330	29	9.64 140	34	0.35 859	9.96 190	20						
40	9.60 359	28	9.64 174	34	0.35 825	9.96 184	19						
41	9.60 388	29	9.64 209	34	0.35 791	9.96 179	18						
42	9.60 417	28	9.64 243	34	0.35 756	9.96 173	17						
43	9.60 445	29	9.64 277	34	0.35 722	9.96 168	16						
44	9.60 474	28	9.64 312	34	0.35 688	9.96 162	15						
45	9.60 503	29	9.64 346	34	0.35 653	9.96 157	14						
46	9.60 532	28	9.64 380	34	0.35 619	9.96 151	13						
47	9.60 560	28	9.64 415	34	0.35 585	9.96 146	12						
48	9.60 589	29	9.64 449	34	0.35 551	9.96 140	11						
49	9.60 618	28	9.64 483	34	0.35 517	9.96 134	10						
50	9.60 646	28	9.64 517	34	0.35 482	9.96 129	9						
51	9.60 675	28	9.64 551	34	0.35 448	9.96 123	8						
52	9.60 703	28	9.64 585	34	0.35 414	9.96 118	7						
53	9.60 732	28	9.64 620	34	0.35 380	9.96 112	6						
54	9.60 760	28	9.64 654	34	0.35 346	9.96 106	5						
55	9.60 789	28	9.64 688	34	0.35 312	9.96 101	4						
56	9.60 817	28	9.64 722	34	0.35 278	9.96 095	3						
57	9.60 846	28	9.64 756	34	0.35 244	9.96 090	2						
58	9.60 874	28	9.64 790	34	0.35 209	9.96 084	1						
59	9.60 903	28	9.64 824	34	0.35 175	9.96 078	0						
60	9.60 931	28	9.64 858	34	0.35 141	9.96 073							
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.						

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
24°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.60 931	28	9.64 858	34	0.35 141	9.96 073	5	60			
1	9.60 959	28	9.64 892	34	0.35 107	9.96 067	5	59			
2	9.60 988	28	9.64 926	34	0.35 073	9.96 062	6	58			
3	9.61 016	28	9.64 960	33	0.35 040	9.96 056	5	57			
4	9.61 044	28	9.64 994	34	0.35 006	9.96 050	5	56			
5	9.61 073	28	9.65 028	34	0.34 972	9.96 045	5	55	34	33	33
6	9.61 101	28	9.65 062	34	0.34 938	9.96 039	6	54	6	3.4	3.3
7	9.61 129	28	9.65 096	34	0.34 904	9.96 033	5	53	7	3.9	3.8
8	9.61 157	28	9.65 129	33	0.34 870	9.96 028	5	52	8	4.3	4.4
9	9.61 186	28	9.65 163	34	0.34 836	9.96 022	6	51	9	5.1	4.9
10	9.61 214	28	9.65 197	34	0.34 802	9.96 016	5	50	10	5.6	5.5
11	9.61 242	28	9.65 231	33	0.34 769	9.96 011	5	49	20	11.3	11.0
12	9.61 270	28	9.65 265	34	0.34 735	9.96 005	6	48	30	17.0	16.5
13	9.61 298	28	9.65 299	34	0.34 701	9.95 999	5	47	40	22.6	22.0
14	9.61 326	28	9.65 332	33	0.34 667	9.95 994	5	46	50	28.3	27.5
15	9.61 354	28	9.65 366	34	0.34 633	9.95 988	6	45			
16	9.61 382	28	9.65 400	33	0.34 600	9.95 982	5	44			
17	9.61 410	28	9.65 433	33	0.34 566	9.95 977	5	43			
18	9.61 438	28	9.65 467	34	0.34 532	9.95 971	6	42			
19	9.61 466	28	9.65 501	33	0.34 499	9.95 965	5	41	28	28	
20	9.61 494	28	9.65 535	34	0.34 465	9.95 959	6	40	6	2.8	2.8
21	9.61 522	27	9.65 568	33	0.34 431	9.95 954	5	39	7	3.3	3.2
22	9.61 550	28	9.65 602	33	0.34 398	9.95 948	6	38	8	3.8	3.7
23	9.61 578	28	9.65 635	33	0.34 364	9.95 942	5	37	9	4.3	4.2
24	9.61 606	28	9.65 669	33	0.34 331	9.95 937	5	36	10	4.7	4.6
25	9.61 634	27	9.65 703	34	0.34 297	9.95 931	6	35	20	9.5	9.3
26	9.61 661	28	9.65 736	33	0.34 263	9.95 925	5	34	30	14.2	14.0
27	9.61 689	27	9.65 770	33	0.34 230	9.95 919	6	33	40	19.0	18.6
28	9.61 717	28	9.65 803	33	0.34 196	9.95 914	5	32	50	23.7	23.3
29	9.61 745	27	9.65 837	33	0.34 163	9.95 908	6	31			
30	9.61 772	28	9.65 870	33	0.34 129	9.95 902	5	30			
31	9.61 800	27	9.65 904	33	0.34 096	9.95 896	6	29			
32	9.61 828	28	9.65 937	33	0.34 062	9.95 891	5	28			
33	9.61 856	27	9.65 971	33	0.34 029	9.95 885	6	27	27	27	
34	9.61 883	27	9.66 004	33	0.33 996	9.95 879	5	26	6	2.7	2.7
35	9.61 911	27	9.66 037	33	0.33 962	9.95 873	6	25	7	3.2	3.1
36	9.61 938	27	9.66 071	33	0.33 929	9.95 867	5	24	8	3.6	3.6
37	9.61 966	28	9.66 104	33	0.33 895	9.95 862	6	23	9	4.1	4.0
38	9.61 994	27	9.66 137	33	0.33 862	9.95 856	5	22	10	4.6	4.5
39	9.62 021	27	9.66 171	33	0.33 829	9.95 850	6	21	20	9.1	9.0
40	9.62 049	27	9.66 204	33	0.33 795	9.95 844	5	20	30	13.7	13.5
41	9.62 076	27	9.66 237	33	0.33 762	9.95 838	6	19	40	18.3	18.0
42	9.62 104	27	9.66 271	33	0.33 729	9.95 833	5	18	50	22.9	22.5
43	9.62 131	27	9.66 304	33	0.33 696	9.95 827	6	17			
44	9.62 158	27	9.66 337	33	0.33 662	9.95 821	5	16			
45	9.62 186	27	9.66 370	33	0.33 629	9.95 815	6	15			
46	9.62 213	27	9.66 404	33	0.33 596	9.95 809	5	14			
47	9.62 241	27	9.66 437	33	0.33 563	9.95 804	6	13	6	0.6	0.5
48	9.62 268	27	9.66 470	33	0.33 529	9.95 798	5	12	7	0.7	0.6
49	9.62 295	27	9.66 503	33	0.33 496	9.95 792	6	11	8	0.8	0.7
50	9.62 323	27	9.66 536	33	0.33 463	9.95 786	5	10	9	0.9	0.8
51	9.62 350	27	9.66 570	33	0.33 430	9.95 780	6	9	10	1.0	0.9
52	9.62 377	27	9.66 603	33	0.33 397	9.95 774	5	8	20	2.0	1.8
53	9.62 404	27	9.66 636	33	0.33 364	9.95 768	6	7	30	3.0	2.7
54	9.62 432	27	9.66 669	33	0.33 331	9.95 763	5	6	40	4.0	3.6
55	9.62 459	27	9.66 702	33	0.33 298	9.95 757	6	5	50	5.0	4.6
56	9.62 486	27	9.66 735	33	0.33 265	9.95 751	5	4			
57	9.62 513	27	9.66 768	33	0.33 232	9.95 745	6	3			
58	9.62 540	27	9.66 801	33	0.33 198	9.95 739	5	2			
59	9.62 567	27	9.66 834	33	0.33 165	9.95 733	6	1			
60	9.62 595	27	9.66 867	33	0.33 132	9.95 727	5	0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.		

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
25°

°	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.			
								60	59	58	57
0	9.62 595	27	9.66 869	32	0.33 132	9.95 727	6	60			
1	9.62 622	27	9.66 900	33	0.33 100	9.95 721	6	59			
2	9.62 649	27	9.66 933	33	0.33 067	9.95 716	6	58			
3	9.62 676	27	9.66 966	33	0.33 034	9.95 710	6	57			
4	9.62 703	27	9.66 999	33	0.33 001	9.95 704	6	56			
5	9.62 730	27	9.67 032	33	0.32 968	9.95 698	6	55			
6	9.62 757	27	9.67 065	32	0.32 935	9.95 692	6	54			
7	9.62 784	27	9.67 097	33	0.32 902	9.95 686	6	53			
8	9.62 811	27	9.67 130	33	0.32 869	9.95 680	6	52			
9	9.62 838	26	9.67 163	33	0.32 836	9.95 674	6	51			
10	9.62 864	27	9.67 196	32	0.32 803	9.95 668	6	50			
11	9.62 891	27	9.67 229	33	0.32 771	9.95 662	6	49			
12	9.62 918	27	9.67 262	32	0.32 738	9.95 656	6	48			
13	9.62 945	26	9.67 294	33	0.32 705	9.95 650	6	47			
14	9.62 972	27	9.67 327	32	0.32 672	9.95 644	6	46			
15	9.62 999	26	9.67 360	33	0.32 640	9.95 638	6	45			
16	9.63 025	27	9.67 393	32	0.32 607	9.95 632	6	44			
17	9.63 052	26	9.67 425	33	0.32 574	9.95 627	6	43			
18	9.63 079	27	9.67 458	32	0.32 541	9.95 621	6	42			
19	9.63 106	26	9.67 491	32	0.32 509	9.95 615	6	41			
20	9.63 132	27	9.67 523	33	0.32 476	9.95 609	6	40			
21	9.63 159	26	9.67 556	32	0.32 443	9.95 603	6	39			
22	9.63 186	26	9.67 589	32	0.32 411	9.95 597	6	38			
23	9.63 212	26	9.67 621	33	0.32 378	9.95 591	6	37			
24	9.63 239	27	9.67 654	32	0.32 345	9.95 585	6	36			
25	9.63 266	26	9.67 687	32	0.32 313	9.95 579	6	35			
26	9.63 292	26	9.67 719	32	0.32 280	9.95 573	6	34			
27	9.63 319	26	9.67 752	32	0.32 248	9.95 567	6	33			
28	9.63 345	26	9.67 784	32	0.32 215	9.95 561	6	32			
29	9.63 372	26	9.67 817	32	0.32 183	9.95 555	6	31			
30	9.63 398	26	9.67 849	32	0.32 150	9.95 549	6	30			
31	9.63 425	26	9.67 882	32	0.32 118	9.95 543	6	29			
32	9.63 451	26	9.67 914	32	0.32 085	9.95 537	6	28			
33	9.63 478	26	9.67 947	32	0.32 053	9.95 530	6	27			
34	9.63 504	26	9.67 979	32	0.32 020	9.95 524	6	26			
35	9.63 530	26	9.68 012	32	0.31 988	9.95 518	6	25			
36	9.63 557	26	9.68 044	32	0.31 955	9.95 512	6	24			
37	9.63 583	26	9.68 077	32	0.31 923	9.95 506	6	23			
38	9.63 609	26	9.68 109	32	0.31 891	9.95 500	6	22			
39	9.63 636	26	9.68 141	32	0.31 858	9.95 494	6	21			
40	9.63 662	26	9.68 174	32	0.31 826	9.95 488	6	20			
41	9.63 688	26	9.68 206	32	0.31 793	9.95 482	6	19			
42	9.63 715	26	9.68 238	32	0.31 761	9.95 476	6	18			
43	9.63 741	26	9.68 271	32	0.31 729	9.95 470	6	17			
44	9.63 767	26	9.68 303	32	0.31 696	9.95 464	6	16			
45	9.63 793	26	9.68 335	32	0.31 664	9.95 458	6	15			
46	9.63 819	26	9.68 368	32	0.31 632	9.95 452	6	14			
47	9.63 846	26	9.68 400	32	0.31 600	9.95 445	6	13			
48	9.63 872	26	9.68 432	32	0.31 567	9.95 439	6	12			
49	9.63 898	26	9.68 464	32	0.31 535	9.95 433	6	11			
50	9.63 924	26	9.68 497	32	0.31 503	9.95 427	6	10			
51	9.63 950	26	9.68 529	32	0.31 471	9.95 421	6	9			
52	9.63 976	26	9.68 561	32	0.31 439	9.95 415	6	8			
53	9.64 002	26	9.68 593	32	0.31 406	9.95 409	6	7			
54	9.64 028	26	9.68 625	32	0.31 374	9.95 403	6	6			
55	9.64 054	26	9.68 657	32	0.31 342	9.95 397	6	5			
56	9.64 080	26	9.68 690	32	0.31 310	9.95 390	6	4			
57	9.64 106	26	9.68 722	32	0.31 278	9.95 384	6	3			
58	9.64 132	26	9.68 754	32	0.31 246	9.95 378	6	2			
59	9.64 158	25	9.68 786	32	0.31 214	9.95 372	6	1			
60	9.64 184		9.68 818	32	0.31 182	9.95 366	6	0			
Log. Cos.								P. P.			

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

26°

										P. P.		
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.					
0	9.64 184	26	9.68 818	32	0.31 182	9.95 366	6	60				
1	9.64 210	26	9.68 850	32	0.31 150	9.95 360	6	59				
2	9.64 236	26	9.68 882	32	0.31 117	9.95 353	6	58				
3	9.64 262	25	9.68 914	32	0.31 085	9.95 347	6	57				
4	9.64 287	25	9.68 946	32	0.31 053	9.95 341	6	56				
5	9.64 313	26	9.68 978	32	0.31 021	9.95 335	6	55				
6	9.64 339	26	9.69 010	32	0.30 989	9.95 329	6	54				
7	9.64 365	25	9.69 042	32	0.30 957	9.95 323	6	53				
8	9.64 391	26	9.69 074	31	0.30 926	9.95 316	6	52				
9	9.64 416	25	9.69 106	32	0.30 894	9.95 310	6	51				
10	9.64 442	26	9.69 138	32	0.30 862	9.95 304	6	50				
11	9.64 468	25	9.69 170	32	0.30 830	9.95 298	6	49				
12	9.64 493	25	9.69 202	32	0.30 798	9.95 292	6	48				
13	9.64 519	26	9.69 234	32	0.30 766	9.95 285	6	47				
14	9.64 545	25	9.69 265	31	0.30 734	9.95 279	6	46				
15	9.64 570	25	9.69 297	32	0.30 702	9.95 273	6	45				
16	9.64 596	25	9.69 329	32	0.30 670	9.95 267	6	44				
17	9.64 622	26	9.69 361	31	0.30 639	9.95 260	6	43				
18	9.64 647	25	9.69 393	32	0.30 607	9.95 254	6	42				
19	9.64 673	25	9.69 425	32	0.30 575	9.95 248	6	41				
20	9.64 698	25	9.69 456	31	0.30 543	9.95 242	6	40				
21	9.64 724	25	9.69 488	32	0.30 511	9.95 235	6	39				
22	9.64 749	25	9.69 520	31	0.30 480	9.95 229	6	38				
23	9.64 775	25	9.69 552	32	0.30 448	9.95 223	6	37				
24	9.64 800	25	9.69 583	31	0.30 416	9.95 217	6	36				
25	9.64 826	25	9.69 615	32	0.30 384	9.95 210	6	35				
26	9.64 851	25	9.69 647	31	0.30 353	9.95 204	6	34				
27	9.64 876	25	9.69 678	31	0.30 321	9.95 198	6	33				
28	9.64 902	25	9.69 710	32	0.30 289	9.95 191	6	32				
29	9.64 927	25	9.69 742	31	0.30 258	9.95 185	6	31				
30	9.64 952	25	9.69 773	31	0.30 226	9.95 179	6	30				
31	9.64 978	25	9.69 805	32	0.30 194	9.95 173	6	29				
32	9.65 003	25	9.69 837	31	0.30 163	9.95 166	6	28				
33	9.65 028	25	9.69 868	31	0.30 131	9.95 160	6	27				
34	9.65 054	25	9.69 900	31	0.30 100	9.95 154	6	26				
35	9.65 079	25	9.69 931	31	0.30 068	9.95 147	6	25				
36	9.65 104	25	9.69 963	31	0.30 037	9.95 141	6	24				
37	9.65 129	25	9.69 994	31	0.30 005	9.95 135	6	23				
38	9.65 155	25	9.70 026	32	0.29 973	9.95 128	6	22				
39	9.65 180	25	9.70 058	31	0.29 942	9.95 122	6	21				
40	9.65 205	25	9.70 089	31	0.29 910	9.95 116	6	20				
41	9.65 230	25	9.70 121	31	0.29 879	9.95 109	6	19				
42	9.65 255	25	9.70 152	31	0.29 847	9.95 103	6	18				
43	9.65 280	25	9.70 183	31	0.29 816	9.95 097	6	17				
44	9.65 305	25	9.70 215	31	0.29 785	9.95 090	6	16				
45	9.65 331	25	9.70 246	31	0.29 753	9.95 084	6	15				
46	9.65 356	25	9.70 278	31	0.29 722	9.95 078	6	14				
47	9.65 381	25	9.70 309	31	0.29 690	9.95 071	6	13				
48	9.65 406	25	9.70 341	31	0.29 659	9.95 065	6	12				
49	9.65 431	25	9.70 372	31	0.29 628	9.95 058	6	11				
50	9.65 456	25	9.70 403	31	0.29 596	9.95 052	6	10				
51	9.65 481	25	9.70 435	31	0.29 565	9.95 046	6	9				
52	9.65 506	25	9.70 466	31	0.29 533	9.95 039	6	8				
53	9.65 530	24	9.70 497	31	0.29 502	9.95 033	6	7				
54	9.65 555	25	9.70 529	31	0.29 471	9.95 026	6	6				
55	9.65 580	25	9.70 560	31	0.29 439	9.95 020	6	5				
56	9.65 605	25	9.70 591	31	0.29 408	9.95 014	6	4				
57	9.65 630	24	9.70 623	31	0.29 377	9.95 007	6	3				
58	9.65 655	25	9.70 654	31	0.29 346	9.95 001	6	2				
59	9.65 680	25	9.70 685	31	0.29 314	9.94 994	6	1				
60	9.65 704	24	9.70 716	31	0.29 283	9.94 988	6	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.	'		P. P.		

3232

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3.2

3.7

4.2

4.8

5.3

10.6

16.0

21.3

26.6

3131

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3.1

3.6

4.1

4.6

5.1

10.3

15.5

20.6

25.8

262525

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2.6

3.0

3.4

3.8

4.2

8.5

12.7

17.0

21.2

2466

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2.4

2.8

3.2

3.7

4.1

8.1

12.2

16.3

20.4

63°

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
27°

										P. P.			
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	u.						
0	9.65 704	25	9.70 716	31	0.29 283	9.94 988	6	60					
1	9.65 729	24	9.70 748	31	0.29 252	9.94 981	6	59					
2	9.65 754	25	9.70 779	31	0.29 221	9.94 975	6	58					
3	9.65 779	24	9.70 810	31	0.29 190	9.94 969	6	57					
4	9.65 803	24	9.70 841	31	0.29 158	9.94 962	6	56					
5	9.65 828	25	9.70 872	31	0.29 127	9.94 956	6	55					
6	9.65 853	24	9.70 903	31	0.29 096	9.94 949	6	54					
7	9.65 878	25	9.70 935	31	0.29 065	9.94 943	6	53					
8	9.65 902	24	9.70 966	31	0.29 034	9.94 936	6	52					
9	9.65 927	24	9.70 997	31	0.29 003	9.94 930	6	51					
10	9.65 951	24	9.71 028	31	0.28 972	9.94 923	6	50					
11	9.65 976	25	9.71 059	31	0.28 940	9.94 917	6	49					
12	9.66 001	24	9.71 090	31	0.28 909	9.94 910	6	48					
13	9.66 025	24	9.71 121	31	0.28 878	9.94 904	6	47					
14	9.66 050	24	9.71 152	31	0.28 847	9.94 897	6	46					
15	9.66 074	24	9.71 183	31	0.28 816	9.94 891	6	45					
16	9.66 099	24	9.71 214	31	0.28 785	9.94 884	6	44					
17	9.66 123	24	9.71 245	31	0.28 754	9.94 878	6	43					
18	9.66 148	24	9.71 276	31	0.28 723	9.94 871	6	42					
19	9.66 172	24	9.71 307	31	0.28 692	9.94 865	6	41					
20	9.66 197	24	9.71 338	31	0.28 661	9.94 858	6	40					
21	9.66 221	24	9.71 369	31	0.28 630	9.94 852	6	39					
22	9.66 246	24	9.71 400	31	0.28 599	9.94 845	6	38					
23	9.66 270	24	9.71 431	31	0.28 568	9.94 839	6	37					
24	9.66 294	24	9.71 462	31	0.28 537	9.94 832	6	36					
25	9.66 319	24	9.71 493	30	0.28 506	9.94 825	7	35					
26	9.66 343	24	9.71 524	31	0.28 476	9.94 819	6	34					
27	9.66 367	24	9.71 555	31	0.28 445	9.94 812	6	33					
28	9.66 392	24	9.71 586	31	0.28 414	9.94 806	6	32					
29	9.66 416	24	9.71 617	31	0.28 383	9.94 799	6	31					
30	9.66 440	24	9.71 647	30	0.28 352	9.94 793	6	30					
31	9.66 465	24	9.71 678	31	0.28 321	9.94 786	6	29					
32	9.66 489	24	9.71 709	31	0.28 290	9.94 779	7	28					
33	9.66 513	24	9.71 740	30	0.28 260	9.94 773	6	27					
34	9.66 537	24	9.71 771	31	0.28 229	9.94 766	6	26					
35	9.66 561	24	9.71 801	30	0.28 198	9.94 760	6	25					
36	9.66 586	24	9.71 832	31	0.28 167	9.94 753	6	24					
37	9.66 610	24	9.71 863	31	0.28 136	9.94 746	7	23					
38	9.66 634	24	9.71 894	30	0.28 106	9.94 740	6	22					
39	9.66 658	24	9.71 925	31	0.28 075	9.94 733	6	21					
40	9.66 682	24	9.71 955	30	0.28 044	9.94 727	6	20					
41	9.66 706	24	9.71 986	30	0.28 014	9.94 720	6	19					
42	9.66 730	24	9.72 017	31	0.27 983	9.94 713	7	18					
43	9.66 754	24	9.72 047	30	0.27 952	9.94 707	6	17					
44	9.66 778	24	9.72 078	31	0.27 921	9.94 700	6	16					
45	9.66 802	24	9.72 109	30	0.27 891	9.94 693	7	15					
46	9.66 826	24	9.72 139	30	0.27 860	9.94 687	6	14					
47	9.66 850	24	9.72 170	30	0.27 830	9.94 680	6	13					
48	9.66 874	24	9.72 201	31	0.27 799	9.94 674	6	12					
49	9.66 898	24	9.72 231	30	0.27 768	9.94 667	7	11					
50	9.66 922	24	9.72 262	30	0.27 738	9.94 660	6	10					
51	9.66 946	24	9.72 292	30	0.27 707	9.94 654	6	9					
52	9.66 970	24	9.72 323	30	0.27 677	9.94 647	7	8					
53	9.66 994	23	9.72 354	31	0.27 646	9.94 640	6	7					
54	9.67 018	24	9.72 384	30	0.27 615	9.94 633	7	6					
55	9.67 042	24	9.72 415	30	0.27 585	9.94 627	6	5					
56	9.67 066	24	9.72 445	30	0.27 554	9.94 620	6	4					
57	9.67 089	23	9.72 476	30	0.27 524	9.94 613	7	3					
58	9.67 113	24	9.72 506	30	0.27 493	9.94 607	6	2					
59	9.67 137	23	9.72 537	30	0.27 463	9.94 600	7	1					
60	9.67 161	24	9.72 567	30	0.27 432	9.94 593	6	0					
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.	'		P. P.			

	31	31	38
6	3.1	3.1	3.6
7	3.7	3.6	3.5
8	4.2	4.1	4.0
9	4.7	4.6	4.6
10	5.2	5.1	5.1
20	10.5	10.3	10.1
30	15.7	15.5	15.2
40	21.0	20.6	20.3
50	26.2	25.8	25.4
	25		
6	2.5		
7	2.9		
8	3.3		
9	3.7		
10	4.1		
20	8.3		
30	12.5		
40	16.6		
50	20.8		
	24	24	23
6	2.4	2.4	2.3
7	2.8	2.8	2.7
8	3.2	3.2	3.1
9	3.7	3.6	3.5
10	4.1	4.0	3.9
20	8.1	8.0	7.8
30	12.2	12.0	11.7
40	16.3	16.0	15.6
50	20.4	20.0	19.6
	7	8	6
6	0.7	0.6	0.6
7	0.8	0.7	0.7
8	0.9	0.8	0.8
9	1.0	1.0	0.9
10	1.1	1.1	1.0
20	2.3	2.1	2.0
30	3.5	3.2	3.0
40	4.6	4.3	4.0
50	5.8	5.4	5.0

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
28°

	Log. Sin.	d.		c. d.	Log. Cot.	Log. Cos.	d.		P. P.			
0	9.67 161	23		36	0.27 432	9.94 593	6	60				
1	9.67 184	24		36	0.27 402	9.94 587	7	59				
2	9.67 208	23		36	0.27 371	9.94 580	6	58				
3	9.67 232	24	9.72 659	30	0.27 341	9.94 573	7	57				
4	9.67 256	23	9.72 689	36	0.27 311	9.94 566	6	56				
5	9.67 279	23	9.72 719	36	0.27 280	9.94 560	7	55	36	30	26	
6	9.67 303	24	9.72 750	36	0.27 250	9.94 553	6	54	6	3.0	3.0	2.1
7	9.67 327	23	9.72 780	36	0.27 219	9.94 546	7	53	7	3.5	3.5	3.1
8	9.67 350	23	9.72 811	36	0.27 189	9.94 539	6	52	8	4.0	4.0	3.1
9	9.67 374	23	9.72 841	30	0.27 159	9.94 533	7	51	9	4.6	4.5	4.1
10	9.67 397	24	9.72 871	36	0.27 128	9.94 526	6	50	10	5.1	5.0	4.1
11	9.67 421	23	9.72 902	36	0.27 098	9.94 519	7	49	20	10.1	10.0	9.1
12	9.67 445	23	9.72 932	36	0.27 067	9.94 512	6	48	30	15.2	15.0	14.1
13	9.67 468	23	9.72 962	30	0.27 037	9.94 506	7	47	40	20.3	20.0	19.1
14	9.67 492	23	9.72 993	36	0.27 007	9.94 499	6	46	50	25.4	25.0	24.6
15	9.67 515	23	9.73 023	36	0.26 976	9.94 492	7	45				
16	9.67 539	23	9.73 053	36	0.26 946	9.94 485	6	44				
17	9.67 562	23	9.73 084	36	0.26 916	9.94 478	7	43				
18	9.67 586	23	9.73 114	30	0.26 886	9.94 472	6	42				
19	9.67 609	23	9.73 144	36	0.26 855	9.94 465	7	41			24	
20	9.67 633	23	9.73 174	30	0.26 825	9.94 458	6	40	6	2.4		
21	9.67 656	23	9.73 205	36	0.26 795	9.94 451	7	39	7	2.8		
22	9.67 679	23	9.73 235	36	0.26 765	9.94 444	6	38	8	3.2		
23	9.67 703	23	9.73 265	30	0.26 734	9.94 437	7	37	9	3.6		
24	9.67 726	23	9.73 295	36	0.26 704	9.94 431	6	36	10	4.0		
25	9.67 750	23	9.73 325	30	0.26 674	9.94 424	7	35	20	8.0		
26	9.67 773	23	9.73 356	36	0.26 644	9.94 417	6	34	30	12.0		
27	9.67 796	23	9.73 386	36	0.26 614	9.94 410	7	33	40	16.0		
28	9.67 819	23	9.73 416	30	0.26 584	9.94 403	6	32	50	20.0		
29	9.67 843	23	9.73 446	36	0.26 553	9.94 396	7	31				
30	9.67 866	23	9.73 476	30	0.26 523	9.94 390	6	30				
31	9.67 889	23	9.73 506	36	0.26 493	9.94 383	7	29				
32	9.67 913	23	9.73 536	30	0.26 463	9.94 376	6	28				
33	9.67 936	23	9.73 567	36	0.26 433	9.94 369	7	27	23	23	22	
34	9.67 959	23	9.73 597	30	0.26 403	9.94 362	6	26	6	2.3	2.3	2.3
35	9.67 982	23	9.73 627	36	0.26 373	9.94 355	7	25	7	2.7	2.7	2.6
36	9.68 005	23	9.73 657	30	0.26 343	9.94 348	6	24	8	3.1	3.0	3.0
37	9.68 029	23	9.73 687	36	0.26 313	9.94 341	7	23	9	3.5	3.4	3.4
38	9.68 052	23	9.73 717	30	0.26 283	9.94 335	6	22	10	3.9	3.8	3.7
39	9.68 075	23	9.73 747	36	0.26 253	9.94 328	7	21	20	7.8	7.6	7.5
40	9.68 098	23	9.73 777	30	0.26 223	9.94 321	6	20	30	11.7	11.5	11.3
41	9.68 121	23	9.73 807	36	0.26 193	9.94 314	7	19	40	15.6	15.3	15.0
42	9.68 144	23	9.73 837	30	0.26 163	9.94 307	6	18	50	19.6	19.1	18.7
43	9.68 167	23	9.73 867	36	0.26 133	9.94 300	7	17				
44	9.68 190	23	9.73 897	30	0.26 103	9.94 293	6	16				
45	9.68 213	23	9.73 927	36	0.26 073	9.94 286	7	15				
46	9.68 236	23	9.73 957	30	0.26 043	9.94 279	6	14				
47	9.68 259	23	9.73 987	36	0.26 013	9.94 272	7	13				
48	9.68 282	23	9.74 017	30	0.25 983	9.94 265	6	12				
49	9.68 305	23	9.74 047	36	0.25 953	9.94 258	7	11	6	0.7	0.6	
50	9.68 328	23	9.74 076	29	0.25 923	9.94 251	6	10	7	0.8	0.7	
51	9.68 351	23	9.74 106	30	0.25 893	9.94 245	7	9	8	0.9	0.8	
52	9.68 374	23	9.74 136	36	0.25 863	9.94 238	6	8	9	1.0	1.0	
53	9.68 397	22	9.74 166	30	0.25 833	9.94 231	7	7	10	1.1	1.1	
54	9.68 420	23	9.74 196	29	0.25 804	9.94 224	6	6	20	2.3	2.1	
55	9.68 443	23	9.74 226	30	0.25 774	9.94 217	7	5	30	3.5	3.2	
56	9.68 466	23	9.74 256	36	0.25 744	9.94 210	6	4	40	4.6	4.3	
57	9.68 488	22	9.74 286	30	0.25 714	9.94 203	7	3	50	5.8	5.4	
58	9.68 511	23	9.74 315	29	0.25 684	9.94 196	6	2				
59	9.68 534	23	9.74 345	30	0.25 654	9.94 189	7	1				
60	9.68 557	22	9.74 375	29	0.25 625	9.94 182	6	0				
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.					P. P.

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

29°

'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.			
0	9.68 557	23	9.74 375	30	0.25 625	9.94 182	7	60			
1	9.68 580	22	9.74 405	30	0.25 595	9.94 175	7	59			
2	9.68 602	23	9.74 435	29	0.25 565	9.94 168	7	58			
3	9.68 625	22	9.74 464	30	0.25 535	9.94 161	7	57			
4	9.68 648	22	9.74 494	29	0.25 505	9.94 154	7	56			
5	9.68 671	23	9.74 524	30	0.25 476	9.94 147	7	55	30	29	29
6	9.68 693	22	9.74 554	29	0.25 446	9.94 140	7	54	6	3.0	2.9
7	9.68 716	23	9.74 583	29	0.25 416	9.94 133	7	53	7	3.5	3.4
8	9.68 739	22	9.74 613	30	0.25 387	9.94 126	7	52	8	4.0	3.8
9	9.68 761	22	9.74 643	29	0.25 357	9.94 118	7	51	9	4.5	4.3
10	9.68 784	23	9.74 672	30	0.25 327	9.94 111	7	50	10	5.0	4.8
11	9.68 807	22	9.74 702	29	0.25 297	9.94 104	7	49	20	10.0	9.6
12	9.68 829	22	9.74 732	29	0.25 268	9.94 097	7	48	30	15.0	14.5
13	9.68 852	22	9.74 761	30	0.25 238	9.94 090	7	47	40	20.0	19.3
14	9.68 874	22	9.74 791	29	0.25 208	9.94 083	7	46	50	25.0	24.1
15	9.68 897	23	9.74 821	29	0.25 179	9.94 076	7	45			
16	9.68 920	22	9.74 850	29	0.25 149	9.94 069	7	44			
17	9.68 942	22	9.74 880	29	0.25 120	9.94 062	7	43			
18	9.68 965	22	9.74 909	30	0.25 090	9.94 055	7	42			
19	9.68 987	22	9.74 939	29	0.25 060	9.94 048	7	41			
20	9.69 010	22	9.74 969	29	0.25 031	9.94 041	7	40	23		
21	9.69 032	22	9.74 998	29	0.25 001	9.94 034	7	39	6	2.3	
22	9.69 055	22	9.75 028	29	0.24 972	9.94 026	7	38	7	2.7	
23	9.69 077	22	9.75 057	29	0.24 942	9.94 019	7	37	8	3.0	
24	9.69 099	22	9.75 087	29	0.24 913	9.94 012	7	36	9	3.4	
25	9.69 122	22	9.75 116	29	0.24 883	9.94 005	7	35	10	3.8	
26	9.69 144	22	9.75 146	29	0.24 854	9.93 998	7	34	20	7.6	
27	9.69 167	22	9.75 175	29	0.24 824	9.93 991	7	33	30	11.5	
28	9.69 189	22	9.75 205	29	0.24 795	9.93 984	7	32	40	15.3	
29	9.69 211	22	9.75 234	29	0.24 765	9.93 977	7	31	50	19.1	
30	9.69 234	22	9.75 264	29	0.24 736	9.93 969	7	30			
31	9.69 256	22	9.75 293	29	0.24 706	9.93 962	7	29			
32	9.69 278	22	9.75 323	29	0.24 677	9.93 955	7	28			
33	9.69 301	22	9.75 352	29	0.24 647	9.93 948	7	27	22	22	21
34	9.69 323	22	9.75 382	29	0.24 618	9.93 941	7	26	6	2.2	2.1
35	9.69 345	22	9.75 411	29	0.24 588	9.93 934	7	25	7	2.6	2.5
36	9.69 367	22	9.75 441	29	0.24 559	9.93 926	7	24	8	3.0	2.8
37	9.69 390	22	9.75 470	29	0.24 529	9.93 919	7	23	9	3.4	3.2
38	9.69 412	22	9.75 499	29	0.24 500	9.93 912	7	22	10	3.7	3.6
39	9.69 434	22	9.75 529	29	0.24 471	9.93 905	7	21	20	7.5	7.1
40	9.69 456	22	9.75 558	29	0.24 441	9.93 898	7	20	30	11.2	10.7
41	9.69 478	22	9.75 588	29	0.24 412	9.93 891	7	19	40	15.0	14.3
42	9.69 500	22	9.75 617	29	0.24 383	9.93 883	7	18	50	18.7	17.9
43	9.69 523	22	9.75 646	29	0.24 353	9.93 876	7	17			
44	9.69 545	22	9.75 676	29	0.24 324	9.93 869	7	16			
45	9.69 567	22	9.75 705	29	0.24 295	9.93 862	7	15			
46	9.69 589	22	9.75 734	29	0.24 265	9.93 854	7	14			
47	9.69 611	22	9.75 764	29	0.24 236	9.93 847	7	13			
48	9.69 633	22	9.75 793	29	0.24 207	9.93 840	7	12	7	7	
49	9.69 655	22	9.75 822	29	0.24 177	9.93 833	7	11	6	0.7	0.7
50	9.69 677	22	9.75 851	29	0.24 148	9.93 826	7	10	7	0.9	0.8
51	9.69 699	22	9.75 881	29	0.24 119	9.93 818	7	9	8	1.0	0.9
52	9.69 721	22	9.75 910	29	0.24 090	9.93 811	7	8	9	1.1	1.0
53	9.69 743	22	9.75 939	29	0.24 060	9.93 804	7	7	10	1.2	1.1
54	9.69 765	22	9.75 968	29	0.24 031	9.93 796	7	6	20	2.5	2.3
55	9.69 787	22	9.75 998	29	0.24 002	9.93 789	7	5	30	3.7	3.5
56	9.69 809	22	9.76 027	29	0.23 973	9.93 782	7	4	40	5.0	4.6
57	9.69 831	21	9.76 056	29	0.23 943	9.93 775	7	3	50	6.2	5.8
58	9.69 853	22	9.76 085	29	0.23 914	9.93 767	7	2			
59	9.69 875	22	9.76 115	29	0.23 885	9.93 760	7	1			
60	9.69 897	22	9.76 144	29	0.23 856	9.93 753	7	0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.		

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

30°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.69 897	22	9.76 144	29	0.23 856	9.93 753	7	40			
1	9.69 919	21	9.76 173	29	0.23 827	9.93 746	7	59			
2	9.69 940	22	9.76 202	29	0.23 797	9.93 738	7	58			
3	9.69 962	22	9.76 231	29	0.23 768	9.93 731	7	57			
4	9.69 984	21	9.76 260	29	0.23 739	9.93 724	7	56			
5	9.70 006	22	9.76 289	29	0.23 710	9.93 716	7	55			
6	9.70 028	22	9.76 319	29	0.23 681	9.93 709	7	54			
7	9.70 050	21	9.76 348	29	0.23 652	9.93 702	7	53			
8	9.70 071	22	9.76 377	29	0.23 623	9.93 694	7	52			
9	9.70 093	21	9.76 406	29	0.23 594	9.93 687	7	51			
10	9.70 115	22	9.76 435	29	0.23 565	9.93 680	7	50			
11	9.70 137	21	9.76 464	29	0.23 535	9.93 672	7	49			
12	9.70 158	21	9.76 493	29	0.23 506	9.93 665	7	48			
13	9.70 180	22	9.76 522	29	0.23 477	9.93 658	7	47			
14	9.70 202	21	9.76 551	29	0.23 448	9.93 650	7	46			
15	9.70 223	21	9.76 580	29	0.23 419	9.93 643	7	45			
16	9.70 245	22	9.76 609	29	0.23 390	9.93 635	7	44			
17	9.70 267	21	9.76 638	29	0.23 361	9.93 628	7	43			
18	9.70 288	21	9.76 667	29	0.23 332	9.93 621	7	42			
19	9.70 310	21	9.76 696	29	0.23 303	9.93 613	7	41			
20	9.70 331	22	9.76 725	29	0.23 274	9.93 606	7	40			
21	9.70 353	21	9.76 754	29	0.23 245	9.93 599	7	39			
22	9.70 375	21	9.76 783	29	0.23 216	9.93 591	7	38			
23	9.70 396	21	9.76 812	29	0.23 187	9.93 584	7	37			
24	9.70 418	21	9.76 841	29	0.23 158	9.93 576	7	36			
25	9.70 439	21	9.76 870	29	0.23 129	9.93 569	7	35			
26	9.70 461	21	9.76 899	29	0.23 101	9.93 562	7	34			
27	9.70 482	21	9.76 928	29	0.23 072	9.93 554	7	33			
28	9.70 504	21	9.76 957	29	0.23 043	9.93 547	7	32			
29	9.70 525	21	9.76 986	29	0.23 014	9.93 539	7	31			
30	9.70 547	21	9.77 015	29	0.22 985	9.93 532	7	30			
31	9.70 568	21	9.77 043	28	0.22 956	9.93 524	7	29			
32	9.70 590	21	9.77 072	29	0.22 927	9.93 517	7	28			
33	9.70 611	21	9.77 101	29	0.22 898	9.93 509	7	27			
34	9.70 632	21	9.77 130	29	0.22 869	9.93 502	7	26			
35	9.70 654	21	9.77 159	28	0.22 841	9.93 495	7	25			
36	9.70 675	21	9.77 188	29	0.22 812	9.93 487	7	24			
37	9.70 696	21	9.77 217	29	0.22 783	9.93 480	7	23			
38	9.70 718	21	9.77 245	28	0.22 754	9.93 472	7	22			
39	9.70 739	21	9.77 274	29	0.22 725	9.93 465	7	21			
40	9.70 760	21	9.77 303	29	0.22 696	9.93 457	7	20			
41	9.70 782	21	9.77 332	28	0.22 668	9.93 450	7	19			
42	9.70 803	21	9.77 361	29	0.22 639	9.93 442	7	18			
43	9.70 824	21	9.77 389	28	0.22 610	9.93 435	7	17			
44	9.70 846	21	9.77 418	29	0.22 581	9.93 427	7	16			
45	9.70 867	21	9.77 447	28	0.22 553	9.93 420	7	15			
46	9.70 888	21	9.77 476	29	0.22 524	9.93 412	7	14			
47	9.70 909	21	9.77 504	28	0.22 495	9.93 405	7	13			
48	9.70 930	21	9.77 533	29	0.22 466	9.93 397	7	12			
49	9.70 952	21	9.77 562	28	0.22 438	9.93 390	7	11			
50	9.70 973	21	9.77 591	29	0.22 409	9.93 382	8	10			
51	9.70 994	21	9.77 619	28	0.22 380	9.93 374	7	9			
52	9.71 015	21	9.77 648	28	0.22 352	9.93 367	7	8			
53	9.71 036	21	9.77 677	29	0.22 323	9.93 359	7	7			
54	9.71 057	21	9.77 705	28	0.22 294	9.93 352	7	6			
55	9.71 078	21	9.77 734	28	0.22 266	9.93 344	7	5			
56	9.71 099	21	9.77 763	29	0.22 237	9.93 337	7	4			
57	9.71 121	21	9.77 791	28	0.22 208	9.93 329	7	3			
58	9.71 142	21	9.77 820	28	0.22 180	9.93 321	8	2			
59	9.71 163	21	9.77 849	29	0.22 151	9.93 314	7	1			
60	9.71 184	21	9.77 877	28	0.22 122	9.93 306	7	0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.		

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
31°

		Log. Sin.		d.	Log. Tan.		c. d.	Log. Cot.		Log. Cos.		d.			P. P.			
0		9.71 184		21	9.77 879		28	0.22 122		9.93 306		7	60					
1		9.71 205		21	9.77 906		28	0.22 094		9.93 299		7	59					
2		9.71 226		21	9.77 934		28	0.22 065		9.93 291		7	58					
3		9.71 247		21	9.77 963		28	0.22 037		9.93 284		8	57					
4		9.71 268		21	9.77 992		29	0.22 008		9.93 276		8	56					
5		9.71 289		21	9.78 020		28	0.21 979		9.93 268		7	55					
6		9.71 310		21	9.78 049		28	0.21 951		9.93 261		7	54					
7		9.71 331		21	9.78 077		28	0.21 922		9.93 253		8	53					
8		9.71 351		20	9.78 106		28	0.21 894		9.93 245		8	52					
9		9.71 372		21	9.78 134		28	0.21 865		9.93 238		7	51					
10		9.71 393		21	9.78 163		28	0.21 837		9.93 230		7	50					
11		9.71 414		21	9.78 191		28	0.21 808		9.93 223		7	49					
12		9.71 435		20	9.78 220		28	0.21 780		9.93 215		8	48					
13		9.71 456		21	9.78 248		28	0.21 751		9.93 207		7	47					
14		9.71 477		21	9.78 277		28	0.21 723		9.93 200		7	46					
15		9.71 498		21	9.78 305		28	0.21 694		9.93 192		8	45					
16		9.71 518		20	9.78 334		28	0.21 666		9.93 184		7	44					
17		9.71 539		21	9.78 362		28	0.21 637		9.93 177		7	43					
18		9.71 560		20	9.78 391		28	0.21 609		9.93 169		8	42					
19		9.71 581		21	9.78 419		28	0.21 580		9.93 161		7	41					
20		9.71 601		20	9.78 448		28	0.21 552		9.93 153		8	40					
21		9.71 622		21	9.78 476		28	0.21 523		9.93 146		7	39					
22		9.71 643		20	9.78 505		28	0.21 495		9.93 138		7	38					
23		9.71 664		21	9.78 533		28	0.21 467		9.93 130		8	37					
24		9.71 684		20	9.78 561		28	0.21 438		9.93 123		7	36					
25		9.71 705		21	9.78 590		28	0.21 410		9.93 115		8	35					
26		9.71 726		20	9.78 618		28	0.21 381		9.93 107		7	34					
27		9.71 746		20	9.78 647		28	0.21 353		9.93 100		7	33					
28		9.71 767		21	9.78 675		28	0.21 325		9.93 092		8	32					
29		9.71 788		20	9.78 703		28	0.21 296		9.93 084		7	31					
30		9.71 808		20	9.78 732		28	0.21 268		9.93 076		8	30					
31		9.71 829		20	9.78 760		28	0.21 239		9.93 069		7	29					
32		9.71 849		20	9.78 788		28	0.21 211		9.93 061		8	28					
33		9.71 870		21	9.78 817		28	0.21 183		9.93 053		7	27					
34		9.71 891		20	9.78 845		28	0.21 154		9.93 045		8	26					
35		9.71 911		20	9.78 873		28	0.21 126		9.93 038		7	25					
36		9.71 932		20	9.78 902		28	0.21 098		9.93 030		8	24					
37		9.71 952		20	9.78 930		28	0.21 070		9.93 022		7	23					
38		9.71 973		20	9.78 958		28	0.21 041		9.93 014		8	22					
39		9.71 993		20	9.78 987		28	0.21 013		9.93 006		8	21					
40		9.72 014		20	9.79 015		28	0.20 985		9.92 999		7	20					
41		9.72 034		20	9.79 043		28	0.20 956		9.92 991		8	19					
42		9.72 055		20	9.79 071		28	0.20 928		9.92 983		7	18					
43		9.72 075		20	9.79 100		28	0.20 900		9.92 975		8	17					
44		9.72 096		20	9.79 128		28	0.20 872		9.92 967		8	16					
45		9.72 116		20	9.79 156		28	0.20 843		9.92 960		7	15					
46		9.72 136		20	9.79 184		28	0.20 815		9.92 952		8	14					
47		9.72 157		20	9.79 213		28	0.20 787		9.92 944		8	13					
48		9.72 177		20	9.79 241		28	0.20 759		9.92 936		7	12					
49		9.72 198		20	9.79 269		28	0.20 731		9.92 928		8	11					
50		9.72 218		20	9.79 297		28	0.20 702		9.92 920		8	10					
51		9.72 238		20	9.79 325		28	0.20 674		9.92 913		7	9					
52		9.72 259		20	9.79 354		28	0.20 646		9.92 905		8	8					
53		9.72 279		20	9.79 382		28	0.20 618		9.92 897		8	7					
54		9.72 299		20	9.79 410		28	0.20 590		9.92 889		7	6					
55		9.72 319		20	9.79 438		28	0.20 561		9.92 881		8	5					
56		9.72 340		20	9.79 466		28	0.20 533		9.92 873		8	4					
57		9.72 360		20	9.79 494		28	0.20 505		9.92 865		8	3					
58		9.72 380		20	9.79 522		28	0.20 477		9.92 858		7	2					
59		9.72 400		20	9.79 551		28	0.20 449		9.92 850		8	1					
60		9.72 421		20	9.79 579		28	0.20 421		9.92 842		8	0					

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24.1

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3.8

4.3

4.7

9.5

14.2

19.0

23.7

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3.7

4.2

4.6

9.3

14.0

18.6

23.3

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4.0

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1.0

1.1

1.2

2.5

3.7

5.0

6.2

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

32°

	Log. Sin.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.72 421		0.20 421	9.92 842	8	00			
1	9.72 441	28	0.20 393	9.92 834	7	59			
2	9.72 461	28	0.20 365	9.92 826	8	58			
3	9.72 481	28	0.20 337	9.92 818	8	57			
4	9.72 501	28	0.20 308	9.92 810	8	56			
5	9.72 522	28	0.20 280	9.92 802	8	55			
6	9.72 542	28	0.20 252	9.92 794	8	54			
7	9.72 562	28	0.20 224	9.92 786	8	53			
8	9.72 582	28	0.20 196	9.92 778	7	52			
9	9.72 602	28	0.20 168	9.92 771	8	51			
10	9.72 622	28	0.20 140	9.92 763	8	50			
11	9.72 642	28	0.20 112	9.92 755	8	49			
12	9.72 662	28	0.20 084	9.92 747	8	48			
13	9.72 682	28	0.20 056	9.92 739	8	47			
14	9.72 702	28	0.20 028	9.92 731	8	46			
15	9.72 723	28	0.20 000	9.92 723	8	45			
16	9.72 743	28	0.19 972	9.92 715	8	44			
17	9.72 763	28	0.19 944	9.92 707	8	43			
18	9.72 783	28	0.19 916	9.92 699	8	42			
19	9.72 802	28	0.19 888	9.92 691	8	41			
20	9.72 822	28	0.19 860	9.92 683	8	40			
21	9.72 842	28	0.19 832	9.92 675	8	39			
22	9.72 862	28	0.19 804	9.92 667	8	38			
23	9.72 882	28	0.19 776	9.92 659	8	37			
24	9.72 902	28	0.19 748	9.92 651	8	36			
25	9.72 922	27	0.19 721	9.92 643	8	35			
26	9.72 942	28	0.19 693	9.92 635	8	34			
27	9.72 962	28	0.19 665	9.92 627	8	33			
28	9.72 982	28	0.19 637	9.92 619	8	32			
29	9.73 002	28	0.19 609	9.92 611	8	31			
30	9.73 021	27	0.19 581	9.92 603	8	30			
31	9.73 041	28	0.19 553	9.92 595	8	29			
32	9.73 061	28	0.19 525	9.92 587	8	28			
33	9.73 081	28	0.19 497	9.92 579	8	27			
34	9.73 101	27	0.19 470	9.92 570	8	26			
35	9.73 120	28	0.19 442	9.92 562	8	25			
36	9.73 140	28	0.19 414	9.92 554	8	24			
37	9.73 160	27	0.19 386	9.92 546	8	23			
38	9.73 180	28	0.19 358	9.92 538	8	22			
39	9.73 199	28	0.19 330	9.92 530	8	21			
40	9.73 219	27	0.19 303	9.92 522	8	20			
41	9.73 239	28	0.19 275	9.92 514	8	19			
42	9.73 258	27	0.19 247	9.92 506	8	18			
43	9.73 278	28	0.19 219	9.92 498	8	17			
44	9.73 298	28	0.19 191	9.92 489	8	16			
45	9.73 317	27	0.19 164	9.92 481	8	15			
46	9.73 337	28	0.19 136	9.92 473	8	14			
47	9.73 357	27	0.19 108	9.92 465	8	13			
48	9.73 376	28	0.19 080	9.92 457	8	12			
49	9.73 396	27	0.19 053	9.92 449	8	11			
50	9.73 415	28	0.19 025	9.92 441	8	10			
51	9.73 435	27	0.18 997	9.92 433	8	9			
52	9.73 455	27	0.18 970	9.92 424	8	8			
53	9.73 474	28	0.18 942	9.92 416	8	7			
54	9.73 494	27	0.18 914	9.92 408	8	6			
55	9.73 513	28	0.18 886	9.92 400	8	5			
56	9.73 533	27	0.18 859	9.92 392	8	4			
57	9.73 552	27	0.18 831	9.92 383	8	3			
58	9.73 572	28	0.18 803	9.92 375	8	2			
59	9.73 591	27	0.18 776	9.92 367	8	1			
60	9.73 611	27	0.18 748	9.92 359	8	0			
	Log. Cos.	c. d.	Log. Tan.	Log. Sin.	d.				

	28	28	27
6	2.8	2.8	2.7
7	3.3	3.2	3.2
8	3.8	3.7	3.6
9	4.3	4.2	4.1
10	4.7	4.6	4.6
20	9.5	9.3	9.1
30	14.2	14.0	13.7
40	19.0	18.6	18.3
50	23.7	23.3	22.9

	20	20	19
6	2.0	2.0	1.9
7	2.4	2.3	2.3
8	2.7	2.6	2.6
9	3.1	3.0	2.9
10	3.4	3.3	3.2
20	6.8	6.6	6.5
30	10.2	10.0	9.7
40	13.6	13.3	13.0
50	17.1	16.6	16.2

	8	8	7
6	0.8	0.8	0.7
7	1.0	0.9	0.9
8	1.1	1.0	1.0
9	1.3	1.2	1.1
10	1.4	1.3	1.2
20	2.8	2.6	2.5
30	4.2	4.0	3.7
40	5.6	5.3	5.0
50	7.1	6.6	6.2

'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	P. P.			
0	9.73 611	19	9.81 251	28	0.18 748	9.92 359	8	60			
1	9.73 630	19	9.81 279	29	0.18 720	9.92 351	8	59			
2	9.73 650	19	9.81 307	29	0.18 693	9.92 342	8	58			
3	9.73 669	19	9.81 334	28	0.18 665	9.92 334	8	57			
4	9.73 688	19	9.81 362	29	0.18 637	9.92 326	8	56			
5	9.73 708	19	9.81 390	29	0.18 610	9.92 318	8	55			
6	9.73 727	19	9.81 417	29	0.18 582	9.92 310	8	54			
7	9.73 746	19	9.81 445	28	0.18 555	9.92 301	8	53			
8	9.73 766	19	9.81 473	29	0.18 527	9.92 293	8	52			
9	9.73 785	19	9.81 500	29	0.18 499	9.92 285	8	51	28	27	27
10	9.73 805	19	9.81 528	29	0.18 472	9.92 277	8	50	6	2.8	2.7
11	9.73 824	19	9.81 555	29	0.18 444	9.92 268	8	49	7	3.2	3.1
12	9.73 843	19	9.81 583	29	0.18 417	9.92 260	8	48	8	3.7	3.6
13	9.73 862	19	9.81 610	29	0.18 389	9.92 252	8	47	9	4.2	4.0
14	9.73 882	19	9.81 638	29	0.18 362	9.92 244	8	46	10	4.6	4.5
15	9.73 901	19	9.81 666	28	0.18 334	9.92 235	8	45	20	9.3	9.0
16	9.73 920	19	9.81 693	29	0.18 306	9.92 227	8	44	30	14.0	13.5
17	9.73 940	19	9.81 721	29	0.18 279	9.92 219	8	43	40	18.6	18.0
18	9.73 959	19	9.81 748	29	0.18 251	9.92 210	8	42	50	23.3	22.5
19	9.73 978	19	9.81 776	29	0.18 224	9.92 202	8	41			
20	9.73 997	19	9.81 803	29	0.18 196	9.92 194	8	40			
21	9.74 016	19	9.81 831	29	0.18 169	9.92 185	8	39			
22	9.74 036	19	9.81 858	29	0.18 141	9.92 177	8	38			
23	9.74 055	19	9.81 886	29	0.18 114	9.92 169	8	37			
24	9.74 074	19	9.81 913	29	0.18 086	9.92 160	8	36			
25	9.74 093	19	9.81 941	29	0.18 059	9.92 152	8	35			
26	9.74 112	19	9.81 968	29	0.18 031	9.92 144	8	34	18	1.9	1.8
27	9.74 131	19	9.81 996	29	0.18 004	9.92 135	8	33	6	1.9	1.8
28	9.74 151	19	9.82 023	29	0.17 976	9.92 127	8	32	7	2.3	2.1
29	9.74 170	19	9.82 051	29	0.17 949	9.92 119	8	31	8	2.6	2.4
30	9.74 189	19	9.82 078	29	0.17 921	9.92 110	8	30	9	2.9	2.8
31	9.74 208	19	9.82 105	27	0.17 894	9.92 102	8	29	10	3.2	3.1
32	9.74 227	19	9.82 133	29	0.17 867	9.92 094	8	28	20	6.5	6.1
33	9.74 246	19	9.82 160	29	0.17 839	9.92 085	8	27	30	9.7	9.2
34	9.74 265	19	9.82 188	29	0.17 812	9.92 077	8	26	40	13.0	12.3
35	9.74 284	19	9.82 215	29	0.17 784	9.92 069	8	25	50	16.2	15.4
36	9.74 303	19	9.82 243	29	0.17 757	9.92 060	8	24			
37	9.74 322	19	9.82 270	29	0.17 729	9.92 052	8	23			
38	9.74 341	18	9.82 297	27	0.17 702	9.92 043	8	22			
39	9.74 360	19	9.82 325	29	0.17 675	9.92 035	8	21			
40	9.74 379	19	9.82 352	29	0.17 647	9.92 027	8	20			
41	9.74 398	19	9.82 380	27	0.17 620	9.92 018	8	19			
42	9.74 417	19	9.82 407	27	0.17 593	9.92 010	8	18			
43	9.74 436	19	9.82 434	29	0.17 565	9.92 001	8	17			
44	9.74 455	19	9.82 462	29	0.17 538	9.91 993	8	16	8	0.8	0.8
45	9.74 474	19	9.82 489	27	0.17 510	9.91 984	8	15	6	0.8	0.8
46	9.74 493	18	9.82 516	27	0.17 483	9.91 976	8	14	7	1.0	0.9
47	9.74 511	19	9.82 544	27	0.17 456	9.91 967	8	13	8	1.1	1.0
48	9.74 530	19	9.82 571	27	0.17 428	9.91 959	8	12	9	1.3	1.2
49	9.74 549	19	9.82 598	27	0.17 401	9.91 951	8	11	10	1.4	1.3
50	9.74 568	18	9.82 626	27	0.17 374	9.91 942	8	10	20	2.8	2.6
51	9.74 587	19	9.82 653	29	0.17 347	9.91 934	8	9	30	4.2	4.0
52	9.74 606	19	9.82 680	29	0.17 319	9.91 925	8	8	40	5.6	5.3
53	9.74 625	18	9.82 708	27	0.17 292	9.91 917	8	7	50	7.1	6.6
54	9.74 643	19	9.82 735	27	0.17 265	9.91 908	8	6			
55	9.74 662	18	9.82 762	27	0.17 237	9.91 900	8	5			
56	9.74 681	19	9.82 789	27	0.17 210	9.91 891	8	4			
57	9.74 700	18	9.82 817	27	0.17 183	9.91 883	8	3			
58	9.74 718	19	9.82 844	29	0.17 156	9.91 874	8	2			
59	9.74 737	18	9.82 871	27	0.17 128	9.91 866	8	1			
60	9.74 756	18	9.82 898	27	0.17 101	9.91 857	8	0			
Log. Cos.		d.	Log. Cot.		c. d.	Log. Tan.		d.	P. P.		

Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.	F. P.		
9.74 756	19	9.82 898	27	0.17 101	9.91 857	60			
9.74 775	18	9.82 926	27	0.17 074	9.91 849	59			
9.74 793	19	9.82 953	27	0.17 047	9.91 840	58			
9.74 812	18	9.82 980	27	0.17 019	9.91 832	57			
9.74 831	18	9.83 007	27	0.16 992	9.91 823	56			
9.74 849	19	9.83 035	27	0.16 965	9.91 814	55			
9.74 868	18	9.83 062	27	0.16 938	9.91 806	54			
9.74 887	18	9.83 089	27	0.16 910	9.91 797	53			
9.74 905	19	9.83 116	27	0.16 883	9.91 789	52			
9.74 924	18	9.83 143	27	0.16 856	9.91 780	51			
9.74 943	18	9.83 171	27	0.16 829	9.91 772	50			
9.74 961	18	9.83 198	27	0.16 802	9.91 763	49			
9.74 980	18	9.83 225	27	0.16 774	9.91 755	48			
9.74 998	18	9.83 252	27	0.16 747	9.91 746	47			
9.75 017	19	9.83 279	27	0.16 720	9.91 737	46			
9.75 036	18	9.83 307	27	0.16 693	9.91 729	45			
9.75 054	18	9.83 334	27	0.16 666	9.91 720	44			
9.75 073	18	9.83 361	27	0.16 639	9.91 712	43			
9.75 091	18	9.83 388	27	0.16 612	9.91 703	42			
9.75 110	18	9.83 415	27	0.16 584	9.91 694	41			
9.75 128	18	9.83 442	27	0.16 557	9.91 686	40			
9.75 147	18	9.83 469	27	0.16 530	9.91 677	39			
9.75 165	18	9.83 496	27	0.16 503	9.91 668	38			
9.75 184	18	9.83 524	27	0.16 476	9.91 660	37			
9.75 202	18	9.83 551	27	0.16 449	9.91 651	36			
9.75 221	18	9.83 578	27	0.16 422	9.91 642	35			
9.75 239	18	9	27	0.16 395	9.91 634	34			
9.75 257	18	9	27	0.16 368	9.91 625	33			
9.75 276	18	9	27	0.16 340	9.91 616	32			
9.75 294	18	9	27	0.16 313	9.91 608	31			
9.75 313	18	9	27	0.16 286	9.91 599	80			
9.75 331	18	9	27	0.16 259	9.91 590	29			
9.75 349	18	9	27	0.16 232	9.91 582	28			
9.75 368	18	9	27	0.16 205	9.91 573	27			
9.75 386	18	9	27	0.16 178	9.91 564	26			
9.75 404	18	9.83 848	27	0.16 151	9.91 556	25			
9.75 423	18	9.83 875	27	0.16 124	9.91 547	24			
9.75 441	18	9.83 902	27	0.16 097	9.91 538	23			
9.75 459	18	9.83 929	27	0.16 070	9.91 529	22			
9.75 478	18	9.83 957	27	0.16 043	9.91 521	21			
9.75 496	18	9.83 984	27	0.16 016	9.91 512	20			
9.75 514	18	9.84 011	27	0.15 989	9.91 503	19			
9.75 532	18	9.84 038	27	0.15 962	9.91 495	18			
9.75 551	18	9.84 065	27	0.15 935	9.91 486	17			
9.75 569	18	9.84 091	26	0.15 908	9.91 477	16			
9.75 587	18	9.84 118	27	0.15 881	9.91 468	15			
9.75 605	18	9.84 145	27	0.15 854	9.91 460	14			
9.75 623	18	9.84 172	27	0.15 827	9.91 451	13			
9.75 642	18	9.84 199	27	0.15 800	9.91 442	12			
9.75 660	18	9.84 226	27	0.15 773	9.91 433	11			
9.75 678	18	9.84 253	27	0.15 746	9.91 424	10			
9.75 696	18	9.84 280	27	0.15 719	9.91 416	9			
9.75 714	18	9.84 307	27	0.15 692	9.91 407	8			
9.75 732	18	9.84 334	27	0.15 665	9.91 398	7			
9.75 750	18	9.84 361	26	0.15 639	9.91 389	6			
9.75 769	18	9.84 388	27	0.15 612	9.91 380	5			
9.75 787	18	9.84 415	27	0.15 585	9.91 372	4			
9.75 805	18	9.84 442	27	0.15 558	9.91 363	3			
9.75 823	18	9.84 469	27	0.15 531	9.91 354	2			
9.75 841	18	9.84 496	27	0.15 504	9.91 345	1			
9.75 859	18	9.84 522	26	0.15 477	9.91 336	0			
Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.	F. P.		

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

35°

	Log. Sin.	d.	Log. Tan.	r. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.75 859	18	9.84 522	27	0.15 477	9.91 336	9	60			
1	9.75 877	18	9.84 549	27	0.15 450	9.91 329	9	59			
2	9.75 895	18	9.84 576	27	0.15 423	9.91 318	9	58			
3	9.75 913	18	9.84 603	26	0.15 396	9.91 310	9	57			
4	9.75 931	18	9.84 630	27	0.15 370	9.91 301	9	56			
5	9.75 949	18	9.84 657	27	0.15 343	9.91 292	9	55			
6	9.75 967	18	9.84 684	27	0.15 316	9.91 283	9	54			
7	9.75 985	18	9.84 711	26	0.15 289	9.91 274	9	53			
8	9.76 003	18	9.84 739	27	0.15 262	9.91 265	9	52			
9	9.76 021	18	9.84 764	27	0.15 235	9.91 256	9	51			
10	9.76 039	18	9.84 791	26	0.15 208	9.91 247	9	50			
11	9.76 057	18	9.84 818	27	0.15 182	9.91 239	9	49			
12	9.76 075	19	9.84 845	26	0.15 155	9.91 230	9	48			
13	9.76 092	19	9.84 871	27	0.15 128	9.91 221	9	47			
14	9.76 110	18	9.84 898	27	0.15 101	9.91 212	9	46			
15	9.76 128	18	9.84 925	26	0.15 074	9.91 203	9	45			
16	9.76 146	19	9.84 952	27	0.15 048	9.91 194	9	44			
17	9.76 164	18	9.84 979	26	0.15 021	9.91 185	9	43			
18	9.76 182	18	9.85 005	27	0.14 994	9.91 176	9	42			
19	9.76 200	19	9.85 032	27	0.14 967	9.91 167	9	41			
20	9.76 217	18	9.85 059	26	0.14 940	9.91 158	9	40			
21	9.76 235	18	9.85 086	27	0.14 914	9.91 149	9	39			
22	9.76 253	19	9.85 113	26	0.14 887	9.91 140	9	38			
23	9.76 271	18	9.85 139	27	0.14 860	9.91 131	9	37			
24	9.76 289	19	9.85 166	26	0.14 833	9.91 122	9	36			
25	9.76 306	18	9.85 193	27	0.14 807	9.91 113	9	35			
26	9.76 324	19	9.85 220	26	0.14 780	9.91 104	9	34			
27	9.76 342	18	9.85 246	27	0.14 753	9.91 095	9	33			
28	9.76 360	19	9.85 273	26	0.14 726	9.91 086	9	32			
29	9.76 377	18	9.85 300	27	0.14 700	9.91 077	9	31			
30	9.76 395	19	9.85 327	26	0.14 673	9.91 068	9	30			
31	9.76 413	18	9.85 353	27	0.14 646	9.91 059	9	29			
32	9.76 431	19	9.85 380	26	0.14 620	9.91 050	9	28			
33	9.76 448	19	9.85 407	26	0.14 593	9.91 041	9	27			
34	9.76 466	18	9.85 433	27	0.14 566	9.91 032	9	26			
35	9.76 484	19	9.85 460	26	0.14 539	9.91 023	9	25			
36	9.76 501	19	9.85 487	26	0.14 513	9.91 014	9	24			
37	9.76 519	19	9.85 513	27	0.14 486	9.91 005	9	23			
38	9.76 536	18	9.85 540	26	0.14 459	9.90 996	9	22			
39	9.76 554	19	9.85 567	27	0.14 433	9.90 987	9	21			
40	9.76 572	19	9.85 594	26	0.14 406	9.90 978	9	20			
41	9.76 589	19	9.85 620	26	0.14 379	9.90 969	9	19			
42	9.76 607	19	9.85 647	26	0.14 353	9.90 960	9	18			
43	9.76 624	18	9.85 673	27	0.14 326	9.90 951	9	17			
44	9.76 642	19	9.85 700	26	0.14 299	9.90 942	9	16			
45	9.76 660	19	9.85 727	26	0.14 273	9.90 933	9	15			
46	9.76 677	19	9.85 753	26	0.14 246	9.90 923	9	14			
47	9.76 695	19	9.85 780	27	0.14 219	9.90 914	9	13			
48	9.76 712	19	9.85 807	26	0.14 193	9.90 905	9	12			
49	9.76 730	19	9.85 833	26	0.14 166	9.90 896	9	11			
50	9.76 747	19	9.85 860	27	0.14 140	9.90 887	9	10			
51	9.76 765	19	9.85 887	26	0.14 113	9.90 878	9	9			
52	9.76 782	19	9.85 913	26	0.14 086	9.90 869	9	8			
53	9.76 800	19	9.85 940	26	0.14 060	9.90 860	9	7			
54	9.76 817	19	9.85 966	26	0.14 033	9.90 850	9	6			
55	9.76 835	17	9.85 993	27	0.14 007	9.90 841	9	5			
56	9.76 852	19	9.86 020	26	0.13 980	9.90 832	9	4			
57	9.76 869	19	9.86 046	26	0.13 953	9.90 823	9	3			
58	9.76 887	19	9.86 073	26	0.13 927	9.90 814	9	2			
59	9.76 904	19	9.86 099	26	0.13 900	9.90 805	9	1			
60	9.76 922	19		26	0.13 874	9.90 796	9	0			
	Log. Cos.	d.		d.	Log. Tan.	Log. Sin.	d.		P. P.		

	27	28
6	2.7	2.6
7	3.1	3.1
8	3.6	3.5
9	4.0	4.0
10	4.5	4.4
20	9.0	8.8
30	13.5	13.2
40	18.0	17.6
50	22.5	22.1

	18	19	17
6	1.8	1.7	1.7
7	2.1	2.0	2.0
8	2.4	2.3	2.2
9	2.7	2.6	2.5
10	3.0	2.9	2.8
20	6.0	5.8	5.6
30	9.0	8.7	8.5
40	12.0	11.6	11.3
50	15.0	14.6	14.1

	9	9	8
6	0.9	0.9	0.8
7	1.1	1.0	1.0
8	1.2	1.2	1.1
9	1.4	1.3	1.3
10	1.6	1.5	1.4
20	3.1	3.0	2.8
30	4.7	4.5	4.2
40	6.3	6.0	5.6
50	7.9	7.5	7.1

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
36°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.			P. P.
0	9.76 922	17	9.86 126	26	0.13 874	9.90 796	8	60	
1	9.76 938	17	9.86 152	26	0.13 849	9.90 788	9	59	
2	9.76 956	17	9.86 179	26	0.13 821	9.90 779	9	58	
3	9.76 974	17	9.86 206	27	0.13 794	9.90 768	9	57	
4	9.76 991	17	9.86 232	26	0.13 767	9.90 759	9	56	
5	9.77 008	17	9.86 259	26	0.13 741	9.90 750	9	55	
6	9.77 026	17	9.86 285	26	0.13 714	9.90 740	9	54	
7	9.77 043	17	9.86 312	26	0.13 688	9.90 731	9	53	
8	9.77 060	17	9.86 338	26	0.13 661	9.90 722	9	52	
9	9.77 078	17	9.86 365	26	0.13 635	9.90 713	9	51	
10	9.77 095	17	9.86 391	26	0.13 608	9.90 703	9	50	
11	9.77 112	17	9.86 418	26	0.13 582	9.90 694	9	49	
12	9.77 130	17	9.86 444	26	0.13 555	— — — 85	9	48	
13	9.77 147	17	9.86 471	26	0.13 529	76	9	47	
14	9.77 164	17	9.86 497	26	0.13 502	66	9	46	
15	9.77 181	17	9.86 524	26	0.13 476	57	9	45	
16	9.77 198	17	9.86 550	26	0.13 449	48	9	44	
17	9.77 216	17	9.86 577	26	0.13 423	39	9	43	
18	9.77 233	17	9.86 603	26	0.13 396	29	9	42	
19	9.77 250	17	9.86 630	26	0.13 370	— — — 20	9	41	
20	9.77 267	17	9.86 656	26	0.13 343	9.90 611	9	40	
21	9.77 284	17	9.86 683	26	0.13 317	9.90 602	9	39	
22	9.77 302	17	9.86 709	26	0.13 290	9.90 592	9	38	
23	9.77 319	17	9.86 736	26	0.13 264	9.90 583	9	37	
24	9.77 336	17	9.86 762	26	0.13 237	9.90 574	9	36	
25	9.77 353	17	9.86 788	26	0.13 211	9.90 564	9	35	
26	9.77 370	17	9.86 815	26	0.13 185	9.90 555	9	34	
27	9.77 387	17	9.86 841	26	0.13 158	9.90 546	9	33	
28	9.77 404	17	9.86 868	26	0.13 132	9.90 536	9	32	
29	9.77 421	17	9.86 894	26	0.13 105	9.90 527	9	31	
30	9.77 439	17	9.86 921	26	0.13 079	9.90 518	9	30	
31	9.77 456	17	9.86 947	26	0.13 052	9.90 508	9	29	
32	9.77 473	17	9.86 973	26	0.13 026	9.90 499	9	28	
33	9.77 490	17	9.87 000	26	0.13 000	9.90 490	9	27	
34	9.77 507	17	9.87 026	26	0.12 973	9.90 480	9	26	
35	9.77 524	17	9.87 053	26	0.12 947	9.90 471	9	25	
36	9.77 541	17	9.87 079	26	0.12 920	9.90 461	9	24	
37	9.77 558	17	9.87 105	26	0.12 894	9.90 452	9	23	
38	9.77 575	17	9.87 132	26	0.12 868	9.90 443	9	22	
39	9.77 592	17	9.87 158	26	0.12 841	9.90 433	9	21	
40	9.77 609	17	9.87 185	26	0.12 815	9.90 424	9	20	
41	9.77 626	17	9.87 211	26	0.12 789	9.90 414	9	19	
42	9.77 643	17	9.87 237	26	0.12 762	9.90 405	9	18	
43	9.77 660	17	9.87 264	26	0.12 736	9.90 396	9	17	
44	9.77 677	17	9.87 290	26	0.12 709	9.90 386	9	16	
45	9.77 693	16	9.87 316	26	0.12 683	9.90 377	9	15	
46	9.77 710	17	9.87 343	26	0.12 657	9.90 367	9	14	
47	9.77 727	17	9.87 369	26	0.12 630	9.90 358	9	13	
48	9.77 744	17	9.87 395	26	0.12 604	9.90 348	9	12	
49	9.77 761	17	9.87 422	26	0.12 578	9.90 339	9	11	
50	9.77 778	16	9.87 448	26	0.12 551	9.90 330	9	10	
51	9.77 795	17	9.87 474	26	0.12 525	9.90 320	9	9	
52	9.77 812	17	9.87 501	26	0.12 499	9.90 311	9	8	
53	9.77 828	16	9.87 527	26	0.12 472	9.90 301	9	7	
54	9.77 845	17	9.87 553	26	0.12 446	9.90 292	9	6	
55	9.77 862	17	9.87 580	26	0.12 420	9.90 282	9	5	
56	9.77 879	16	9.87 606	26	0.12 393	9.90 273	9	4	
57	9.77 896	17	9.87 632	26	0.12 367	9.90 263	9	3	
58	9.77 913	17	9.87 659	26	0.12 341	9.90 254	9	2	
59	9.77 929	16	9.87 685	26	0.12 315	9.90 244	9	1	
60	9.77 946	17	9.87 711	26	0.12 288	9.90 235	9	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

	27	28	26
6	2.7	2.6	2.6
7	3.1	3.1	3.0
8	3.6	3.5	3.4
9	4.0	4.0	3.9
10	4.5	4.4	4.3
20	9.0	8.8	8.6
30	13.5	13.2	13.0
40	18.0	17.6	17.3
50	22.5	22.1	21.6

	19	17	16
6	1.9	1.7	1.6
7	2.0	2.0	1.9
8	2.3	2.2	2.2
9	2.6	2.5	2.5
10	2.9	2.8	2.7
20	5.8	5.6	5.5
30	8.9	8.5	8.2
40	11.6	11.3	11.0
50	14.6	14.1	13.7

	8	9
6	0.9	0.9
7	1.1	1.0
8	1.2	1.2
9	1.4	1.3
10	1.6	1.5
20	3.1	3.0
30	4.7	4.5
40	6.3	6.0
50	7.9	7.5

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

37°

	Log. Sin.	d.	Log. Tan.	r. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.77 946	16	9.87 711	26	0.12 288	9.90 235	60		
1	9.77 963	17	9.87 737	26	0.12 262	9.90 223	59		
2	9.77 980	16	9.87 764	26	0.12 236	9.90 216	58		
3	9.77 996	17	9.87 790	26	0.12 209	9.90 206	57		
4	9.78 013	16	9.87 816	26	0.12 183	9.90 196	56		
5	9.78 030	16	9.87 843	26	0.12 157	9.90 187	55		
6	9.78 046	17	9.87 869	26	0.12 131	9.90 177	54		
7	9.78 063	16	9.87 895	26	0.12 104	9.90 168	53		
8	9.78 080	17	9.87 921	26	0.12 078	9.90 158	52		
9	9.78 097	16	9.87 948	26	0.12 052	9.90 149	51		
10	9.78 113	16	9.87 974	26	0.12 026	9.90 139	50		
11	9.78 130	17	9.88 000	26	0.11 999	9.90 130	49		
12	9.78 147	16	9.88 026	26	0.11 973	9.90 120	48		
13	9.78 163	16	9.88 053	26	0.11 947	9.90 110	47		
14	9.78 180	16	9.88 079	26	0.11 921	9.90 101	46		
15	9.78 196	16	9.88 105	26	0.11 895	9.90 091	45		
16	9.78 213	17	9.88 131	26	0.11 868	9.90 082	44		
17	9.78 230	16	9.88 157	26	0.11 842	9.90 072	43		
18	9.78 246	16	9.88 184	26	0.11 816	9.90 062	42		
19	9.78 263	16	9.88 210	26	0.11 790	9.90 053	41		
20	9.78 279	16	9.88 236	26	0.11 763	9.90 043	40		
21	9.78 296	16	9.88 262	26	0.11 737	9.90 033	39		
22	9.78 312	16	9.88 288	26	0.11 711	9.90 024	38		
23	9.78 329	17	9.88 315	26	0.11 685	9.90 014	37		
24	9.78 346	16	9.88 341	26	0.11 659	9.90 004	36		
25	9.78 362	16	9.88 367	26	0.11 633	9.89 995	35		
26	9.78 379	16	9.88 393	26	0.11 606	9.89 985	34		
27	9.78 395	16	9.88 419	26	0.11 580	9.89 975	33		
28	9.78 412	16	9.88 445	26	0.11 554	9.89 966	32		
29	9.78 428	16	9.88 472	26	0.11 528	9.89 956	31		
30	9.78 444	16	9.88 498	26	0.11 502	9.89 946	30		
31	9.78 461	16	9.88 524	26	0.11 476	9.89 937	29		
32	9.78 477	16	9.88 550	26	0.11 449	9.89 927	28		
33	9.78 494	16	9.88 576	26	0.11 423	9.89 917	27		
34	9.78 510	16	9.88 602	26	0.11 397	9.89 908	26		
35	9.78 527	16	9.88 629	26	0.11 371	9.89 898	25		
36	9.78 543	16	9.88 655	26	0.11 345	9.89 888	24		
37	9.78 559	16	9.88 681	26	0.11 319	9.89 878	23		
38	9.78 576	16	9.88 707	26	0.11 293	9.89 869	22		
39	9.78 592	16	9.88 733	26	0.11 266	9.89 859	21		
40	9.78 609	16	9.88 759	26	0.11 240	9.89 849	20		
41	9.78 625	16	9.88 785	26	0.11 214	9.89 839	19		
42	9.78 641	16	9.88 811	26	0.11 188	9.89 830	18		
43	9.78 658	16	9.88 838	26	0.11 162	9.89 820	17		
44	9.78 674	16	9.88 864	26	0.11 136	9.89 810	16		
45	9.78 690	16	9.88 890	26	0.11 110	9.89 800	15		
46	9.78 707	16	9.88 916	26	0.11 084	9.89 791	14		
47	9.78 723	16	9.88 942	26	0.11 058	9.89 781	13		
48	9.78 739	16	9.88 968	26	0.11 032	9.89 771	12		
49	9.78 755	16	9.88 994	26	0.11 005	9.89 761	11		
50	9.78 772	16	9.89 020	26	0.10 979	9.89 751	10		
51	9.78 788	16	9.89 046	26	0.10 953	9.89 742	9		
52	9.78 804	16	9.89 072	26	0.10 927	9.89 732	8		
53	9.78 821	16	9.89 098	26	0.10 901	9.89 722	7		
54	9.78 837	16	9.89 124	26	0.10 875	9.89 712	6		
55	9.78 853	16	9.89 150	26	0.10 849	9.89 702	5		
56	9.78 869	16	9.89 177	26	0.10 823	9.89 692	4		
57	9.78 885	16	9.89 203	26	0.10 797	9.89 683	3		
58	9.78 902	16	9.89 229	26	0.10 771	9.89 673	2		
59	9.78 918	16	9.89 255	26	0.10 745	9.89 663	1		
60	9.78 934	16	9.89 281	26	0.10 719	9.89 653	0		
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

	26	26
6	2.6	2.6
7	3.1	3.8
8	3.5	3.4
9	4.0	3.9
10	4.4	4.3
20	8.8	8.6
30	13.2	13.0
40	17.6	17.3
50	22.1	21.6

	17	18	16
6	1.7	1.6	1.6
7	2.0	1.9	1.8
8	2.2	2.2	2.1
9	2.5	2.5	2.4
10	2.8	2.7	2.6
20	5.6	5.5	5.3
30	8.5	8.2	8.0
40	11.3	11.0	10.6
50	14.1	13.7	13.3

	20	9
6	1.0	0.9
7	1.1	1.1
8	1.3	1.2
9	1.5	1.4
10	1.6	1.6
20	3.3	3.1
30	5.0	4.7
40	6.6	6.3
50	8.3	7.9

52°

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

38°

S. S.								P. P.		
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.			
0	9.78 934	16	9.89 281	26	0.10 719	9.89 653	9	60		
1	9.78 950	16	9.89 307	26	0.10 693	9.89 643	10	59		
2	9.78 966	16	9.89 333	26	0.10 667	9.89 633	10	58		
3	9.78 982	16	9.89 359	26	0.10 641	9.89 623	10	57		
4	9.78 999	16	9.89 385	26	0.10 615	9.89 613	9	56		
5	9.79 015	16	9.89 411	26	0.10 589	9.89 604	10	55		
6	9.79 031	16	9.89 437	26	0.10 563	9.89 594	10	54		
7	9.79 047	16	9.89 463	26	0.10 537	9.89 584	10	53		
8	9.79 063	16	9.89 489	26	0.10 511	9.89 574	10	52		
9	9.79 079	16	9.89 515	26	0.10 485	9.89 564	10	51		
10	9.79 095	16	9.89 541	26	0.10 459	9.89 554	9	50		
11	9.79 111	16	9.89 567	26	0.10 433	9.89 544	10	49		
12	9.79 127	16	9.89 593	26	0.10 407	9.89 534	10	48		
13	9.79 143	16	9.89 619	26	0.10 381	9.89 524	10	47		
14	9.79 159	16	9.89 645	26	0.10 355	9.89 514	10	46		
15	9.79 175	16	9.89 671	26	0.10 329	9.89 504	10	45		
16	9.79 191	16	9.89 697	26	0.10 303	9.89 494	10	44		
17	9.79 207	16	9.89 723	26	0.10 277	9.89 484	10	43		
18	9.79 223	16	9.89 749	26	0.10 251	9.89 474	10	42		
19	9.79 239	16	9.89 775	26	0.10 225	9.89 464	10	41		
20	9.79 255	16	9.89 801	26	0.10 199	9.89 454	10	40		
21	9.79 271	16	9.89 827	26	0.10 173	9.89 444	10	39		
22	9.79 287	16	9.89 853	26	0.10 147	9.89 434	10	38		
23	9.79 303	16	9.89 879	26	0.10 121	9.89 424	10	37		
24	9.79 319	16	9.89 905	26	0.10 095	9.89 414	10	36		
25	9.79 335	16	9.89 931	26	0.10 069	9.89 404	10	35		
26	9.79 351	16	9.89 957	25	0.10 043	9.89 394	10	34		
27	9.79 367	15	9.89 982	26	0.10 017	9.89 384	10	33		
28	9.79 383	16	9.90 008	26	0.09 991	9.89 374	10	32		
29	9.79 399	16	9.90 034	26	0.09 965	9.89 364	10	31		
30	9.79 415	16	9.90 060	26	0.09 939	9.89 354	10	80		
31	9.79 431	15	9.90 086	26	0.09 913	9.89 344	10	29		
32	9.79 446	16	9.90 112	26	0.09 887	9.89 334	10	28		
33	9.79 462	16	9.90 138	25	0.09 861	9.89 324	10	27		
34	9.79 478	15	9.90 164	26	0.09 836	9.89 314	10	26		
35	9.79 494	16	9.90 190	26	0.09 810	9.89 304	10	25		
36	9.79 510	16	9.90 216	26	0.09 784	9.89 294	10	24		
37	9.79 526	15	9.90 242	26	0.09 758	9.89 284	10	23		
38	9.79 541	16	9.90 268	26	0.09 732	9.89 274	10	22		
39	9.79 557	16	9.90 294	25	0.09 706	9.89 264	10	21		
40	9.79 573	15	9.90 319	26	0.09 680	9.89 253	10	20		
41	9.79 589	16	9.90 345	26	0.09 654	9.89 243	10	19		
42	9.79 605	15	9.90 371	26	0.09 628	9.89 233	10	18		
43	9.79 620	16	9.90 397	25	0.09 602	9.89 223	10	17		
44	9.79 636	15	9.90 423	26	0.09 577	9.89 213	10	16		
45	9.79 652	16	9.90 449	26	0.09 551	9.89 203	10	15		
46	9.79 668	15	9.90 475	26	0.09 525	9.89 193	10	14		
47	9.79 683	16	9.90 501	25	0.09 499	9.89 182	10	13		
48	9.79 699	15	9.90 526	26	0.09 473	9.89 172	10	12		
49	9.79 715	15	9.90 552	26	0.09 447	9.89 162	10	11		
50	9.79 730	16	9.90 578	26	0.09 421	9.89 152	10	10		
51	9.79 746	15	9.90 604	25	0.09 395	9.89 142	10	9		
52	9.79 762	15	9.90 630	26	0.09 370	9.89 132	10	8		
53	9.79 777	16	9.90 656	26	0.09 344	9.89 121	10	7		
54	9.79 793	15	9.90 682	25	0.09 318	9.89 111	10	6		
55	9.79 809	15	9.90 707	26	0.09 292	9.89 101	10	5		
56	9.79 824	16	9.90 733	26	0.09 266	9.89 091	10	4		
57	9.79 840	15	9.90 759	26	0.09 240	9.89 081	10	3		
58	9.79 856	15	9.90 785	25	0.09 214	9.89 070	10	2		
59	9.79 871	15	9.90 811	26	0.09 189	9.89 060	10	1		
60	9.79 887	15	9.90 837	26	0.09 163	9.89 050	10	0		
								P. P.		

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
39°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.79 887	16	9.90 837	26	0.09 163	9.89 050	18	60	
1	9.79 903	15	9.90 863	25	0.09 137	9.89 040	10	59	
2	9.79 918	15	9.90 888	26	0.09 111	9.89 030	10	58	
3	9.79 934	15	9.90 914	25	0.09 085	9.89 016	10	57	
4	9.79 949	15	9.90 940	25	0.09 060	9.89 009	10	56	
5	9.79 965	15	9.90 966	26	0.09 034	9.88 999	10	55	
6	9.79 980	15	9.90 992	25	0.09 008	9.88 989	10	54	
7	9.79 996	15	9.91 017	26	0.08 982	9.88 978	10	53	
8	9.80 011	15	9.91 043	26	0.08 956	9.88 968	10	52	
9	9.80 027	15	9.91 069	25	0.08 930	9.88 958	10	51	
10	9.80 042	15	9.91 095	26	0.08 905	9.88 947	10	50	
11	9.80 058	15	9.91 121	25	0.08 879	9.88 937	10	49	
12	9.80 073	15	9.91 146	26	0.08 853	9.88 927	10	48	
13	9.80 089	15	9.91 172	25	0.08 827	9.88 917	10	47	
14	9.80 104	15	9.91 198	26	0.08 802	9.88 906	10	46	
15	9.80 120	15	9.91 224	26	0.08 776	9.88 896	10	45	
16	9.80 135	15	9.91 250	25	0.08 750	9.88 886	10	44	
17	9.80 151	15	9.91 275	26	0.08 724	9.88 875	10	43	
18	9.80 166	15	9.91 301	25	0.08 698	9.88 865	10	42	
19	9.80 182	15	9.91 327	26	0.08 673	9.88 855	10	41	
20	9.80 197	15	9.91 353	25	0.08 647	9.88 844	10	40	
21	9.80 213	15	9.91 378	26	0.08 621	9.88 834	10	39	
22	9.80 228	15	9.91 404	25	0.08 595	9.88 823	10	38	
23	9.80 243	15	9.91 430	26	0.08 570	9.88 813	10	37	
24	9.80 259	15	9.91 456	25	0.08 544	9.88 803	10	36	
25	9.80 274	15	9.91 481	26	0.08 518	9.88 792	10	35	
26	9.80 289	15	9.91 507	25	0.08 492	9.88 782	10	34	
27	9.80 305	15	9.91 533	26	0.08 467	9.88 772	10	33	
28	9.80 320	15	9.91 559	25	0.08 441	9.88 761	10	32	
29	9.80 335	15	9.91 584	26	0.08 415	9.88 751	10	31	
30	9.80 351	15	9.91 610	25	0.08 389	9.88 740	10	30	
31	9.80 366	15	9.91 636	26	0.08 363	9.88 730	10	29	
32	9.80 381	15	9.91 662	25	0.08 337	9.88 720	10	28	
33	9.80 397	15	9.91 687	26	0.08 311	9.88 709	10	27	
34	9.80 412	15	9.91 713	25	0.08 286	9.88 699	10	26	
35	9.80 427	15	9.91 739	26	0.08 261	9.88 688	10	25	
36	9.80 443	15	9.91 765	25	0.08 235	9.88 678	10	24	
37	9.80 458	15	9.91 790	26	0.08 209	9.88 667	10	23	
38	9.80 473	15	9.91 816	25	0.08 183	9.88 657	10	22	
39	9.80 488	15	9.91 842	26	0.08 158	9.88 646	10	21	
40	9.80 504	15	9.91 867	25	0.08 132	9.88 636	10	20	
41	9.80 519	15	9.91 893	26	0.08 106	9.88 625	10	19	
42	9.80 534	15	9.91 919	25	0.08 081	9.88 615	10	18	
43	9.80 549	15	9.91 945	26	0.08 055	9.88 604	10	17	
44	9.80 564	15	9.91 970	25	0.08 029	9.88 594	10	16	
45	9.80 580	15	9.91 996	26	0.08 004	9.88 583	10	15	
46	9.80 595	15	9.92 022	25	0.07 978	9.88 573	10	14	
47	9.80 610	15	9.92 047	26	0.07 952	9.88 562	10	13	
48	9.80 625	15	9.92 073	25	0.07 926	9.88 552	10	12	
49	9.80 640	15	9.92 099	26	0.07 901	9.88 541	10	11	
50	9.80 655	15	9.92 124	25	0.07 875	9.88 531	10	10	
51	9.80 671	15	9.92 150	26	0.07 849	9.88 520	10	9	
52	9.80 686	15	9.92 176	25	0.07 824	9.88 510	10	8	
53	9.80 701	15	9.92 201	26	0.07 798	9.88 499	10	7	
54	9.80 716	15	9.92 227	25	0.07 772	9.88 489	10	6	
55	9.80 731	15	9.92 253	26	0.07 747	9.88 478	10	5	
56	9.80 746	15	9.92 278	25	0.07 721	9.88 467	10	4	
57	9.80 761	15	9.92 304	26	0.07 695	9.88 457	10	3	
58	9.80 776	15	9.92 330	25	0.07 670	9.88 446	10	2	
59	9.80 791	15	9.92 355	26	0.07 644	9.88 436	10	1	
60	9.80 806	15	9.92 381	26	0.07 618	9.88 425	10	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

	26	25
6	2.6	2.5
7	3.0	3.0
8	3.4	3.4
9	3.9	3.8
10	4.3	4.2
20	8.6	8.5
30	13.0	12.7
40	17.3	17.0
50	21.6	21.2

	16	15	15
6	1.6	1.5	1.5
7	1.8	1.8	1.7
8	2.1	2.0	2.0
9	2.4	2.3	2.2
10	2.6	2.6	2.5
20	5.3	5.1	5.0
30	8.0	7.7	7.5
40	10.6	10.3	10.0
50	13.3	12.9	12.5

	11	10	10
6	1.1	1.0	1.0
7	1.3	1.2	1.1
8	1.4	1.4	1.3
9	1.6	1.6	1.5
10	1.8	1.7	1.6
20	3.6	3.5	3.3
30	5.5	5.2	5.0
40	7.3	7.0	6.6
50	9.1	8.7	8.3

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

40°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.
0	9.80 806	15	9.92 381	25	0.07 618	9.88 425	10	60	
1	9.80 822	15	9.92 407	25	0.07 593	9.88 415	11	59	
2	9.80 837	15	9.92 432	26	0.07 567	9.88 404	10	58	
3	9.80 852	15	9.92 458	25	0.07 541	9.88 393	10	57	
4	9.80 867	15	9.92 484	25	0.07 516	9.88 383	10	56	
5	9.80 882	15	9.92 509	25	0.07 490	9.88 372	11	55	
6	9.80 897	15	9.92 535	26	0.07 465	9.88 361	10	54	
7	9.80 912	15	9.92 561	25	0.07 439	9.88 351	10	53	
8	9.80 927	15	9.92 586	25	0.07 413	9.88 340	11	52	
9	9.80 942	15	9.92 612	26	0.07 388	9.88 329	10	51	
10	9.80 957	15	9.92 638	25	0.07 362	9.88 319	10	50	
11	9.80 972	15	9.92 663	25	0.07 336	9.88 308	11	49	
12	9.80 987	15	9.92 689	25	0.07 311	9.88 297	10	48	
13	9.81 001	15	9.92 714	26	0.07 285	9.88 286	10	47	
14	9.81 016	15	9.92 740	25	0.07 259	9.88 275	11	46	
15	9.81 031	15	9.92 766	25	0.07 234	9.88 264	10	45	
16	9.81 046	15	9.92 791	25	0.07 208	9.88 253	10	44	
17	9.81 061	15	9.92 817	25	0.07 183	9.88 242	11	43	
18	9.81 076	15	9.92 842	25	0.07 157	9.88 231	10	42	
19	9.81 091	15	9.92 868	25	0.07 131	9.88 220	11	41	
20	9.81 106	15	9.92 894	25	0.07 106	9.88 209	10	40	
21	9.81 121	15	9.92 919	25	0.07 080	9.88 198	11	39	
22	9.81 136	15	9.92 945	26	0.07 055	9.88 187	10	38	
23	9.81 150	15	9.92 971	25	0.07 029	9.88 176	11	37	
24	9.81 165	15	9.92 996	25	0.07 003	9.88 165	10	36	
25	9.81 180	15	9.93 022	25	0.06 978	9.88 154	11	35	
26	9.81 195	15	9.93 047	25	0.06 952	9.88 143	10	34	
27	9.81 210	15	9.93 073	25	0.06 927	9.88 132	11	33	
28	9.81 225	15	9.93 098	26	0.06 901	9.88 121	10	32	
29	9.81 239	15	9.93 124	25	0.06 875	9.88 110	11	31	
30	9.81 254	15	9.93 150	25	0.06 850	9.88 100	10	30	
31	9.81 269	15	9.93 175	25	0.06 824	9.88 089	11	29	
32	9.81 284	15	9.93 201	25	0.06 799	9.88 078	11	28	
33	9.81 299	15	9.93 226	25	0.06 773	9.88 067	10	27	
34	9.81 313	15	9.93 252	26	0.06 748	9.88 056	11	26	
35	9.81 328	15	9.93 278	25	0.06 722	9.88 045	11	25	
36	9.81 343	15	9.93 303	25	0.06 696	9.88 034	10	24	
37	9.81 358	15	9.93 329	25	0.06 671	9.88 023	11	23	
38	9.81 372	15	9.93 354	25	0.06 645	9.88 012	11	22	
39	9.81 387	15	9.93 380	25	0.06 620	9.88 001	10	21	
40	9.81 402	15	9.93 405	25	0.06 594	9.87 990	11	20	
41	9.81 416	15	9.93 431	25	0.06 569	9.87 979	11	19	
42	9.81 431	15	9.93 456	25	0.06 543	9.87 968	11	18	
43	9.81 446	15	9.93 482	25	0.06 518	9.87 957	10	17	
44	9.81 460	15	9.93 508	26	0.06 492	9.87 946	11	16	
45	9.81 475	15	9.93 533	25	0.06 466	9.87 935	11	15	
46	9.81 490	15	9.93 559	25	0.06 441	9.87 924	11	14	
47	9.81 504	15	9.93 584	25	0.06 415	9.87 913	10	13	
48	9.81 519	15	9.93 610	25	0.06 390	9.87 902	11	12	
49	9.81 534	15	9.93 635	25	0.06 364	9.87 891	11	11	
50	9.81 548	15	9.93 661	25	0.06 339	9.87 880	11	10	
51	9.81 563	15	9.93 686	25	0.06 313	9.87 869	11	9	
52	9.81 578	15	9.93 712	25	0.06 288	9.87 858	11	8	
53	9.81 592	15	9.93 737	25	0.06 262	9.87 847	10	7	
54	9.81 607	15	9.93 763	25	0.06 237	9.87 836	11	6	
55	9.81 621	15	9.93 788	25	0.06 211	9.87 825	11	5	
56	9.81 636	15	9.93 814	25	0.06 186	9.87 814	11	4	
57	9.81 650	15	9.93 840	26	0.06 160	9.87 803	11	3	
58	9.81 665	15	9.93 865	25	0.06 134	9.87 792	11	2	
59	9.81 680	15	9.93 891	25	0.06 109	9.87 781	11	1	
60	9.81 694	15	9.93 916	25	0.06 083	9.87 770	11	0	
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.

	26	25
6	2.6	2.3
7	3.0	3.0
8	3.4	3.4
9	3.9	3.8
10	4.3	4.2
20	8.6	8.5
30	13.0	12.7
40	17.3	17.0
50	21.6	21.2

	15	15	14
6	1.5	1.5	1.4
7	1.8	1.7	1.7
8	2.0	2.0	1.9
9	2.3	2.2	2.2
10	2.6	2.5	2.4
20	5.1	5.0	4.8
30	7.7	7.5	7.2
40	10.3	10.0	9.6
50	12.9	12.5	12.1

	11	10
6	1.1	1.0
7	1.3	1.2
8	1.4	1.4
9	1.6	1.6
10	1.8	1.7
20	3.6	3.5
30	5.5	5.2
40	7.3	7.0
50	9.1	8.7

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TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

41°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.	
0	9.81 694	14	9.93 916	25	0.06 083	9.87 778	11	60		
1	9.81 709	14	9.93 942	25	0.06 058	9.87 767	11	59		
2	9.81 723	14	9.93 969	25	0.06 032	9.87 756	11	58		
3	9.81 738	14	9.93 993	25	0.06 007	9.87 745	11	57		
4	9.81 752	14	9.94 018	25	0.05 981	9.87 734	11	56		
5	9.81 767	14	9.94 044	25	0.05 956	9.87 723	11	55		
6	9.81 781	14	9.94 069	25	0.05 930	9.87 712	11	54		
7	9.81 796	14	9.94 095	25	0.05 905	9.87 701	11	53		
8	9.81 810	14	9.94 120	25	0.05 879	9.87 690	11	52		
9	9.81 824	14	9.94 146	25	0.05 854	9.87 679	11	51	25	25
10	9.81 839	14	9.94 171	25	0.05 828	9.87 668	11	50	6	2.5
11	9.81 853	14	9.94 197	25	0.05 803	9.87 657	11	49	7	3.0
12	9.81 868	14	9.94 222	25	0.05 777	9.87 645	11	48	8	3.4
13	9.81 882	14	9.94 248	25	0.05 752	9.87 634	11	47	9	3.8
14	9.81 897	14	9.94 273	25	0.05 726	9.87 623	11	46	10	4.2
15	9.81 911	14	9.94 299	25	0.05 701	9.87 612	11	45	20	8.5
16	9.81 925	14	9.94 324	25	0.05 675	9.87 601	11	44	30	12.7
17	9.81 940	14	9.94 350	25	0.05 650	9.87 590	11	43	40	17.0
18	9.81 954	14	9.94 375	25	0.05 625	9.87 579	11	42	50	21.2
19	9.81 969	14	9.94 400	25	0.05 599	9.87 568	11	41		
20	9.81 983	14	9.94 426	25	0.05 574	9.87 557	11	40		
21	9.81 997	14	9.94 451	25	0.05 548	9.87 546	11	39		
22	9.82 012	14	9.94 477	25	0.05 523	9.87 535	11	38		
23	9.82 026	14	9.94 502	25	0.05 497	9.87 524	11	37		
24	9.82 040	14	9.94 528	25	0.05 472	9.87 513	11	36		
25	9.82 055	14	9.94 553	25	0.05 446	9.87 502	11	35		
26	9.82 069	14	9.94 579	25	0.05 421	9.87 491	11	34		
27	9.82 083	14	9.94 604	25	0.05 395	9.87 479	11	33	14	14
28	9.82 098	14	9.94 630	25	0.05 370	9.87 468	11	32	6	1.4
29	9.82 112	14	9.94 655	25	0.05 344	9.87 457	11	31	7	1.7
30	9.82 126	14	9.94 681	25	0.05 319	9.87 445	11	30	8	1.9
31	9.82 140	14	9.94 706	25	0.05 293	9.87 434	11	29	9	2.2
32	9.82 155	14	9.94 732	25	0.05 268	9.87 423	11	28	10	2.4
33	9.82 169	14	9.94 757	25	0.05 243	9.87 412	11	27	20	4.8
34	9.82 183	14	9.94 782	25	0.05 217	9.87 401	11	26	30	7.2
35	9.82 197	14	9.94 808	25	0.05 192	9.87 389	11	25	40	9.6
36	9.82 212	14	9.94 833	25	0.05 166	9.87 378	11	24	50	12.1
37	9.82 226	14	9.94 859	25	0.05 141	9.87 367	11	23		
38	9.82 240	14	9.94 884	25	0.05 115	9.87 356	11	22		
39	9.82 254	14	9.94 910	25	0.05 090	9.87 345	11	21		
40	9.82 269	14	9.94 935	25	0.05 064	9.87 333	11	20		
41	9.82 283	14	9.94 961	25	0.05 039	9.87 322	11	19		
42	9.82 297	14	9.94 986	25	0.05 014	9.87 311	11	18		
43	9.82 311	14	9.95 011	25	0.04 988	9.87 300	11	17		
44	9.82 325	14	9.95 037	25	0.04 963	9.87 288	11	16	11	11
45	9.82 339	14	9.95 062	25	0.04 937	9.87 277	11	15	6	1.1
46	9.82 354	14	9.95 088	25	0.04 912	9.87 266	11	14	7	1.3
47	9.82 368	14	9.95 113	25	0.04 886	9.87 254	11	13	8	1.5
48	9.82 382	14	9.95 139	25	0.04 861	9.87 243	11	12	9	1.7
49	9.82 396	14	9.95 164	25	0.04 836	9.87 232	11	11	10	1.9
50	9.82 410	14	9.95 189	25	0.04 810	9.87 221	11	10	20	3.8
51	9.82 424	14	9.95 215	25	0.04 785	9.87 209	11	9	30	5.7
52	9.82 438	14	9.95 240	25	0.04 759	9.87 198	11	8	40	7.6
53	9.82 452	14	9.95 266	25	0.04 734	9.87 187	11	7	50	9.6
54	9.82 467	14	9.95 291	25	0.04 708	9.87 175	11	6		
55	9.82 481	14	9.95 316	25	0.04 683	9.87 164	11	5		
56	9.82 495	14	9.95 342	25	0.04 658	9.87 153	11	4		
57	9.82 509	14	9.95 367	25	0.04 632	9.87 141	11	3		
58	9.82 523	14	9.95 393	25	0.04 607	9.87 130	11	2		
59	9.82 537	14	9.95 418	25	0.04 581	9.87 118	11	1		
60	9.82 551	14	9.95 443	25	0.04 556	9.87 107	11	0		
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.	

18°

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.
42°

	Log. Sin.	d	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.82 551	14	9.95 443	25	0.04 556	9.87 107	11	60			
1	9.82 565	14	9.95 469	25	0.04 531	9.87 096	11	59			
2	9.82 579	14	9.95 494	25	0.04 505	9.87 084	11	58			
3	9.82 593	14	9.95 520	25	0.04 480	9.87 073	11	57			
4	9.82 607	14	9.95 545	25	0.04 454	9.87 062	11	56			
5	9.82 621	14	9.95 571	25	0.04 429	9.87 050	11	55			
6	9.82 635	14	9.95 596	25	0.04 404	9.87 039	11	54			
7	9.82 649	14	9.95 621	25	0.04 378	9.87 027	11	53			
8	9.82 663	14	9.95 647	25	0.04 353	9.87 016	11	52			
9	9.82 677	14	9.95 672	25	0.04 327	9.87 004	11	51			
10	9.82 691	14	9.95 697	25	0.04 302	9.86 993	11	50			
11	9.82 705	14	9.95 723	25	0.04 277	9.86 982	11	49			
12	9.82 719	14	9.95 748	25	0.04 251	9.86 970	11	48			
13	9.82 733	13	9.95 774	25	0.04 226	9.86 959	11	47			
14	9.82 746	14	9.95 799	25	0.04 200	9.86 947	11	46			
15	9.82 760	14	9.95 824	25	0.04 175	9.86 936	11	45			
16	9.82 774	14	9.95 850	25	0.04 150	9.86 924	11	44			
17	9.82 788	14	9.95 875	25	0.04 124	9.86 913	11	43			
18	9.82 802	13	9.95 901	25	0.04 099	9.86 901	11	42			
19	9.82 816	14	9.95 926	25	0.04 074	9.86 890	11	41			
20	9.82 830	14	9.95 951	25	0.04 048	9.86 878	11	40			
21	9.82 844	14	9.95 977	25	0.04 023	9.86 867	11	39			
22	9.82 858	13	9.96 002	25	0.03 997	9.86 855	11	38			
23	9.82 871	14	9.96 027	25	0.03 972	9.86 844	11	37			
24	9.82 885	14	9.96 053	25	0.03 947	9.86 832	11	36			
25	9.82 899	13	9.96 078	25	0.03 921	9.86 821	11	35			
26	9.82 913	14	9.96 104	25	0.03 896	9.86 809	11	34			
27	9.82 927	13	9.96 129	25	0.03 871	9.86 798	12	33			
28	9.82 940	14	9.96 154	25	0.03 845	9.86 786	11	32			
29	9.82 954	14	9.96 180	25	0.03 820	9.86 774	11	31			
30	9.82 968	13	9.96 205	25	0.03 795	9.86 763	11	30			
31	9.82 982	14	9.96 230	25	0.03 769	9.86 751	11	29			
32	9.82 996	13	9.96 256	25	0.03 744	9.86 740	11	28			
33	9.83 009	14	9.96 281	25	0.03 718	9.86 728	12	27			
34	9.83 023	13	9.96 306	25	0.03 693	9.86 716	11	26			
35	9.83 037	14	9.96 332	25	0.03 668	9.86 705	11	25			
36	9.83 051	13	9.96 357	25	0.03 642	9.86 693	11	24			
37	9.83 064	14	9.96 383	25	0.03 617	9.86 682	11	23			
38	9.83 078	13	9.96 408	25	0.03 592	9.86 670	12	22			
39	9.83 092	14	9.96 433	25	0.03 566	9.86 658	11	21			
40	9.83 106	13	9.96 459	25	0.03 541	9.86 647	11	20			
41	9.83 119	13	9.96 484	25	0.03 516	9.86 635	12	19			
42	9.83 133	14	9.96 509	25	0.03 490	9.86 623	11	18			
43	9.83 147	13	9.96 535	25	0.03 465	9.86 612	11	17			
44	9.83 160	13	9.96 560	25	0.03 440	9.86 600	12	16			
45	9.83 174	14	9.96 585	25	0.03 414	9.86 588	11	15			
46	9.83 188	13	9.96 611	25	0.03 389	9.86 577	11	14			
47	9.83 201	13	9.96 636	25	0.03 364	9.86 565	12	13			
48	9.83 215	14	9.96 661	25	0.03 338	9.86 553	11	12			
49	9.83 229	13	9.96 687	25	0.03 313	9.86 542	12	11			
50	9.83 242	13	9.96 712	25	0.03 287	9.86 530	11	10			
51	9.83 256	13	9.96 737	25	0.03 262	9.86 518	11	9			
52	9.83 269	14	9.96 763	25	0.03 237	9.86 507	12	8			
53	9.83 283	13	9.96 788	25	0.03 211	9.86 495	11	7			
54	9.83 297	13	9.96 813	25	0.03 186	9.86 483	12	6			
55	9.83 310	13	9.96 839	25	0.03 161	9.86 471	11	5			
56	9.83 324	13	9.96 864	25	0.03 135	9.86 460	12	4			
57	9.83 337	13	9.96 889	25	0.03 110	9.86 448	11	3			
58	9.83 351	14	9.96 915	25	0.03 085	9.86 436	12	2			
59	9.83 365	13	9.96 940	25	0.03 059	9.86 424	12	1			
60	9.83 378		9.96 965	25	0.03 034	9.86 412		0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.				
										</	

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS
43°

	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.		P. P.		
0	9.83 378	13	9.96 965	25	0.03 034	9.86 412	11	60			
1	9.83 392	13	9.96 991	25	0.03 009	9.86 401	12	59			
2	9.83 405	13	9.97 016	25	0.02 984	9.86 389	11	58			
3	9.83 419	13	9.97 041	25	0.02 958	9.86 377	12	57			
4	9.83 432	13	9.97 067	25	0.02 933	9.86 365	11	56			
5	9.83 446	13	9.97 092	25	0.02 908	9.86 354	12	55			
6	9.83 459	13	9.97 117	25	0.02 882	9.86 342	12	54			
7	9.83 473	13	9.97 143	25	0.02 857	9.86 330	11	53			
8	9.83 486	13	9.97 168	25	0.02 832	9.86 318	12	52			
9	9.83 500	13	9.97 193	25	0.02 806	9.86 306	12	51			
10	9.83 513	13	9.97 219	25	0.02 781	9.86 294	12	50			
11	9.83 527	13	9.97 244	25	0.02 756	9.86 282	11	49			
12	9.83 540	13	9.97 269	25	0.02 730	9.86 271	12	48			
13	9.83 554	13	9.97 295	25	0.02 705	9.86 259	12	47			
14	9.83 567	13	9.97 320	25	0.02 680	9.86 247	11	46			
15	9.83 580	13	9.97 345	25	0.02 654	9.86 235	12	45			
16	9.83 594	13	9.97 370	25	0.02 629	9.86 223	12	44			
17	9.83 607	13	9.97 396	25	0.02 604	9.86 211	12	43			
18	9.83 621	13	9.97 421	25	0.02 578	9.86 199	12	42			
19	9.83 634	13	9.97 446	25	0.02 553	9.86 187	11	41			
20	9.83 647	13	9.97 472	25	0.02 528	9.86 176	12	40			
21	9.83 661	13	9.97 497	25	0.02 502	9.86 164	12	39			
22	9.83 674	13	9.97 522	25	0.02 477	9.86 152	12	38			
23	9.83 688	13	9.97 548	25	0.02 452	9.86 140	12	37			
24	9.83 701	13	9.97 573	25	0.02 427	9.86 128	12	36			
25	9.83 714	13	9.97 598	25	0.02 401	9.86 116	12	35			
26	9.83 728	13	9.97 624	25	0.02 376	9.86 104	12	34			
27	9.83 741	13	9.97 649	25	0.02 351	9.86 092	12	33			
28	9.83 754	13	9.97 674	25	0.02 325	9.86 080	12	32			
29	9.83 768	13	9.97 699	25	0.02 300	9.86 068	12	31			
30	9.83 781	13	9.97 725	25	0.02 275	9.86 056	12	30			
31	9.83 794	13	9.97 750	25	0.02 249	9.86 044	12	29			
32	9.83 808	13	9.97 775	25	0.02 224	9.86 032	12	28			
33	9.83 821	13	9.97 801	25	0.02 199	9.86 020	12	27			
34	9.83 834	13	9.97 826	25	0.02 174	9.86 008	12	26			
35	9.83 847	13	9.97 851	25	0.02 148	9.85 996	12	25			
36	9.83 861	13	9.97 877	25	0.02 123	9.85 984	12	24			
37	9.83 874	13	9.97 902	25	0.02 098	9.85 972	12	23			
38	9.83 887	13	9.97 927	25	0.02 072	9.85 960	12	22			
39	9.83 900	13	9.97 952	25	0.02 047	9.85 948	12	21			
40	9.83 914	13	9.97 978	25	0.02 022	9.85 936	12	20			
41	9.83 927	13	9.98 003	25	0.01 996	9.85 924	12	19			
42	9.83 940	13	9.98 028	25	0.01 971	9.85 912	12	18			
43	9.83 953	13	9.98 054	25	0.01 946	9.85 900	12	17			
44	9.83 967	13	9.98 079	25	0.01 921	9.85 887	12	16			
45	9.83 980	13	9.98 104	25	0.01 895	9.85 875	12	15			
46	9.83 993	13	9.98 129	25	0.01 870	9.85 863	12	14			
47	9.84 006	13	9.98 155	25	0.01 845	9.85 851	12	13			
48	9.84 019	13	9.98 180	25	0.01 819	9.85 839	12	12			
49	9.84 033	13	9.98 205	25	0.01 794	9.85 827	12	11			
50	9.84 046	13	9.98 231	25	0.01 769	9.85 815	12	10			
51	9.84 059	13	9.98 256	25	0.01 744	9.85 803	12	9			
52	9.84 072	13	9.98 281	25	0.01 718	9.85 791	12	8			
53	9.84 085	13	9.98 306	25	0.01 693	9.85 778	12	7			
54	9.84 098	13	9.98 332	25	0.01 668	9.85 766	12	6			
55	9.84 111	13	9.98 357	25	0.01 642	9.85 754	12	5			
56	9.84 124	13	9.98 382	25	0.01 617	9.85 742	12	4			
57	9.84 138	13	9.98 408	25	0.01 592	9.85 730	12	3			
58	9.84 151	13	9.98 433	25	0.01 567	9.85 718	12	2			
59	9.84 164	13	9.98 458	25	0.01 541	9.85 705	12	1			
60	9.84 177	13	9.98 483	25	0.01 516	9.85 693	12	0			
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.		P. P.		

	25	25
6	2.5	2.5
7	3.0	2.9
8	3.4	3.3
9	3.8	3.7
10	4.2	4.1
20	8.5	8.3
30	12.7	12.5
40	17.0	16.6
50	21.2	20.8

	13	13
6	1.3	1.3
7	1.6	1.5
8	1.8	1.7
9	2.0	1.9
10	2.2	2.1
20	4.5	4.3
30	6.7	6.5
40	9.0	8.6
50	11.2	10.8

	12	12	11
6	1.2	1.2	1.1
7	1.4	1.4	1.3
8	1.6	1.6	1.5
9	1.9	1.8	1.7
10	2.1	2.0	1.9
20	4.1	4.0	3.8
30	6.2	6.0	5.7
40	8.3	8.0	7.6
50	10.4	10.0	9.6

TABLE VII.—LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS.

44°

								P. P.		
'	Log. Sin.	d.	Log. Tan.	c. d.	Log. Cot.	Log. Cos.	d.			
0	9.84 177		9.98 483	25	0.01 516	9.85 693	12	60		
1	9.84 190	13	9.98 509	25	0.01 491	9.85 681	12	59		
2	9.84 203	13	9.98 534	25	0.01 465	9.85 669	12	58		
3	9.84 216	13	9.98 559	25	0.01 440	9.85 657	12	57		
4	9.84 229	13	9.98 585	25	0.01 415	9.85 644	12	56		
5	9.84 242	13	9.98 610	25	0.01 390	9.85 632	12	55		
6	9.84 255	13	9.98 635	25	0.01 364	9.85 620	12	54		
7	9.84 268	13	9.98 660	25	0.01 339	9.85 608	12	53		
8	9.84 281	13	9.98 686	25	0.01 314	9.85 595	12	52		
9	9.84 294	13	9.98 711	25	0.01 289	9.85 583	12	51		
10	9.84 307	13	9.98 736	25	0.01 263	9.85 571	12	50		
11	9.84 320	13	9.98 762	25	0.01 238	9.85 559	12	49		
12	9.84 333	13	9.98 787	25	0.01 213	9.85 546	12	48		
13	9.84 346	13	9.98 812	25	0.01 187	9.85 534	12	47		
14	9.84 359	13	9.98 837	25	0.01 162	9.85 522	12	46		
15	9.84 372	13	9.98 863	25	0.01 137	9.85 509	12	45		
16	9.84 385	13	9.98 888	25	0.01 112	9.85 497	12	44		
17	9.84 398	13	9.98 913	25	0.01 086	9.85 485	12	43		
18	9.84 411	13	9.98 938	25	0.01 061	9.85 472	12	42		
19	9.84 424	12	9.98 964	25	0.01 036	9.85 460	12	41		
20	9.84 437	13	9.98 989	25	0.01 010	9.85 448	12	40		
21	9.84 450	13	9.99 014	25	0.00 985	9.85 435	12	39		
22	9.84 463	13	9.99 040	25	0.00 960	9.85 423	12	38		
23	9.84 476	13	9.99 065	25	0.00 935	9.85 411	12	37		
24	9.84 489	13	9.99 090	25	0.00 909	9.85 398	12	36		
25	9.84 502	12	9.99 115	25	0.00 884	9.85 386	12	35		
26	9.84 514	13	9.99 141	25	0.00 859	9.85 374	12	34		
27	9.84 527	13	9.99 166	25	0.00 834	9.85 361	12	33		
28	9.84 540	13	9.99 191	25	0.00 808	9.85 349	12	32		
29	9.84 553	12	9.99 216	25	0.00 783	9.85 336	12	31		
30	9.84 566	13	9.99 242	25	0.00 758	9.85 324	12	30		
31	9.84 579	13	9.99 267	25	0.00 733	9.85 312	12	29		
32	9.84 592	12	9.99 292	25	0.00 707	9.85 299	12	28		
33	9.84 604	13	9.99 318	25	0.00 682	9.85 287	12	27		
34	9.84 617	13	9.99 343	25	0.00 657	9.85 274	12	26		
35	9.84 630	12	9.99 368	25	0.00 631	9.85 262	12	25		
36	9.84 643	13	9.99 393	25	0.00 606	9.85 249	12	24		
37	9.84 656	13	9.99 419	25	0.00 581	9.85 237	12	23		
38	9.84 669	12	9.99 444	25	0.00 556	9.85 224	12	22		
39	9.84 681	13	9.99 469	25	0.00 530	9.85 212	12	21		
40	9.84 694	12	9.99 494	25	0.00 505	9.85 199	12	20		
41	9.84 707	13	9.99 520	25	0.00 480	9.85 187	12	19		
42	9.84 720	12	9.99 545	25	0.00 455	9.85 174	12	18		
43	9.84 732	13	9.99 570	25	0.00 429	9.85 162	12	17		
44	9.84 745	12	9.99 595	25	0.00 404	9.85 149	12	16		
45	9.84 758	13	9.99 621	25	0.00 379	9.85 137	12	15		
46	9.84 771	12	9.99 646	25	0.00 353	9.85 124	12	14		
47	9.84 783	13	9.99 671	25	0.00 328	9.85 112	12	13		
48	9.84 796	12	9.99 697	25	0.00 303	9.85 099	12	12		
49	9.84 809	13	9.99 722	25	0.00 278	9.85 087	12	11		
50	9.84 822	12	9.99 747	25	0.00 252	9.85 074	12	10		
51	9.84 834	12	9.99 772	25	0.00 227	9.85 062	12	9		
52	9.84 847	13	9.99 798	25	0.00 202	9.85 049	12	8		
53	9.84 860	12	9.99 823	25	0.00 177	9.85 037	13	7		
54	9.84 872	12	9.99 848	25	0.00 151	9.85 024	12	6		
55	9.84 885	13	9.99 873	25	0.00 126	9.85 011	12	5		
56	9.84 898	12	9.99 899	25	0.00 101	9.84 999	12	4		
57	9.84 910	12	9.99 924	25	0.00 076	9.84 986	12	3		
58	9.84 923	13	9.99 949	25	0.00 050	9.84 974	13	2		
59	9.84 936	12	9.99 974	25	0.00 025	9.84 961	12	1		
60	9.84 948		0.00 000	25	0.00 000	9.84 948		0		
	Log. Cos.	d.	Log. Cot.	c. d.	Log. Tan.	Log. Sin.	d.			P. P.

	25	25
6	2.5	2.5
7	3.0	2.9
8	3.4	3.3
9	3.8	3.7
10	4.2	4.1
20	8.5	8.3
30	12.7	12.5
40	17.0	16.6
50	21.2	20.8

	13	13
6	1.3	1.3
7	1.6	1.5
8	1.8	1.7
9	2.0	1.9
10	2.2	2.1
20	4.5	4.3
30	6.7	6.5
40	9.0	8.6
50	11.2	10.8

	12	12
6	1.2	1.2
7	1.4	1.4
8	1.6	1.6
9	1.9	1.8
10	2.1	2.0
20	4.1	4.0
30	6.2	6.0
40	8.3	8.0
50	10.4	10.0

45°

TABLE VIII.

LOGARITHMIC VERSED SINES AND EXTERNAL
SECANTS.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

0°

1°

'	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	'
0	—∞		—∞		6.18271		6.18278		0
1	2.62642	60206	2.62642	60206	.19707	1435	.19714	1436	1
2	3.22848	35218	3.22848	35218	.21119	1412	.21126	1412	2
3	3.58066	24987	3.58066	24987	.22509	1389	.22516	1390	3
4	3.83054	19382	3.83054	19382	.23877	1368	.23884	1368	4
5	4.02436	15836	4.02436	15836	6.25223	1346	6.25231	1347	5
6	.18272	13389	.18272	13389	.26549	1326	.26557	1326	6
7	.31662	11598	.31662	11598	.27856	1306	.27864	1306	7
8	.43260	10230	.43260	10230	.29142	1286	.29151	1287	8
9	.53490	9151	.53491	9151	.30410	1268	.30419	1268	9
10	4.62642	8278	4.62642	8279	6.31660	1250	6.31669	1250	10
11	.70920	7558	.70921	7557	.32892	1232	.32901	1232	11
12	.78478	6953	.78478	6952	.34107	1214	.34116	1215	12
13	.85431	6437	.85431	6437	.35305	1198	.35315	1198	13
14	.91868	5992	.91868	5993	.36487	1182	.36497	1182	14
15	4.97860	5603	4.97861	5603	6.37653	1166	6.37663	1166	15
16	5.03466	5266	5.03466	5266	.38803	1150	.38814	1151	16
17	.08732	4964	.08732	4964	.39938	1135	.39949	1135	17
18	.13696	4696	.13697	4696	.41059	1121	.41070	1121	18
19	.18393	4455	.18393	4456	.42163	1106	.42177	1106	19
20	5.22848	4238	5.22849	4238	6.43258	1093	6.43270	1093	20
21	.27086	4040	.27087	4040	.44337	1078	.44349	1079	21
22	.31126	3861	.31127	3861	.45403	1066	.45415	1066	22
23	.34987	3697	.34988	3697	.46455	1052	.46468	1053	23
24	.38684	3543	.38685	3543	.47496	1040	.47509	1040	24
25	5.42230	3406	5.42231	3407	6.48524	1028	6.48537	1028	25
26	.45636	3278	.45638	3278	.49539	1015	.49553	1016	26
27	.48915	3158	.48916	3159	.50544	1004	.50557	1004	27
28	.52073	3048	.52075	3048	.51536	992	.51550	993	28
29	.55121	2944	.55123	2945	.52518	981	.52532	982	29
30	5.58066	2848	5.58068	2848	6.53488	970	6.53503	970	30
31	.60914	2757	.60916	2758	.54448	960	.54463	960	31
32	.63672	2672	.63674	2672	.55397	949	.55413	950	32
33	.66344	2593	.66346	2593	.56336	939	.56352	939	33
34	.68937	2518	.68940	2517	.57265	929	.57281	929	34
35	5.71455	2447	5.71457	2447	6.58184	919	6.58201	919	35
36	.73902	2379	.73904	2380	.59093	909	.59110	909	36
37	.76282	2316	.76284	2316	.59993	900	.60011	900	37
38	.78598	2256	.78601	2256	.60884	891	.60902	891	38
39	.80854	2199	.80857	2199	.61766	882	.61784	882	39
40	5.83053	2145	5.83056	2145	6.62639	872	6.62657	873	40
41	.85198	2093	.85201	2093	.63503	864	.63522	864	41
42	.87291	2044	.87295	2043	.64359	855	.64378	856	42
43	.89335	1996	.89338	1997	.65206	847	.65226	848	43
44	.91332	1952	.91335	1952	.66045	839	.66065	839	44
45	5.93284	1909	5.93288	1909	6.66876	831	6.66897	831	45
46	.95193	1868	.95197	1868	.67700	823	.67720	823	46
47	.97061	1829	.97065	1829	.68515	815	.68536	816	47
48	5.98890	1790	5.98894	1791	.69323	808	.69345	808	48
49	6.00680	1755	6.00685	1755	.70124	800	.70145	800	49
50	6.02435	1720	6.02440	1720	6.70917	793	6.70939	794	50
51	.04155	1686	.04160	1687	.71703	786	.71725	786	51
52	.05842	1654	.05847	1654	.72482	779	.72505	779	52
53	.07496	1623	.07501	1623	.73254	772	.73277	772	53
54	.09120	1594	.09125	1594	.74019	765	.74043	765	54
55	6.10714	1565	6.10719	1565	6.74777	758	6.74802	759	55
56	.12279	1537	.12284	1537	.75529	752	.75554	752	56
57	.13816	1511	.13822	1511	.76275	745	.76300	746	57
58	.15327	1484	.15333	1485	.77014	739	.77040	739	58
59	.16811	1460	.16818	1460	.77747	733	.77773	733	59
60	6.18271		6.18278		6.78474	726	6.78500	727	60
'	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	'

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

2°

3°

'	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	'
0	6.78474	721	6.78500	721	7.13687	481	7.13746	481	0
1	.79195	714	.79221	715	.14168	478	.14228	479	1
2	.79909	709	.79937	709	.14646	475	.14707	476	2
3	.80618	703	.80646	703	.15122	473	.15183	474	3
4	.81322	697	.81350	698	.15595	470	.15657	471	4
5	6.82019	692	6.82048	692	7.16066	468	7.16129	469	5
6	.82711	686	.82740	687	.16534	466	.16598	466	6
7	.83398	681	.83427	682	.17000	463	.17064	464	7
8	.84079	676	.84109	676	.17463	460	.17528	461	8
9	.84755	670	.84785	671	.17923	458	.17989	459	9
10	6.85425	665	6.85457	666	7.18382	455	7.18448	456	10
11	.86091	660	.86123	660	.18837	453	.18905	454	11
12	.86751	655	.86783	656	.19291	451	.19359	452	12
13	.87407	650	.87439	651	.19742	448	.19811	449	13
14	.88057	646	.88090	646	.20191	446	.20260	447	14
15	6.88703	641	6.88737	641	7.20637	444	7.20707	445	15
16	.89344	636	.89378	636	.21081	442	.21152	442	16
17	.89980	631	.90015	632	.21523	440	.21595	440	17
18	.90612	627	.90647	628	.21963	437	.22035	438	18
19	.91239	622	.91275	623	.22400	435	.22473	436	19
20	6.91862	618	6.91898	618	7.22836	433	7.22909	434	20
21	.92480	613	.92516	614	.23269	431	.23343	431	21
22	.93093	609	.93131	610	.23700	429	.23775	429	22
23	.93703	605	.93741	605	.24129	426	.24204	427	23
24	.94308	601	.94346	601	.24555	424	.24632	425	24
25	6.94909	597	6.94948	597	7.24980	422	7.25057	423	25
26	.95506	592	.95545	593	.25402	420	.25480	421	26
27	.96099	589	.96139	589	.25823	418	.25902	419	27
28	.96688	584	.96728	585	.26241	416	.26321	417	28
29	.97272	581	.97313	581	.26658	414	.26738	415	29
30	6.97853	577	6.97895	577	7.27072	412	7.27153	413	30
31	.98430	573	.98472	574	.27485	410	.27567	411	31
32	.99004	569	.99046	570	.27895	409	.27978	409	32
33	6.99573	565	6.99616	566	.28304	406	.28387	407	33
34	7.00139	562	7.00182	563	.28711	405	.28795	405	34
35	7.00701	558	7.00745	559	7.29116	402	7.29200	404	35
36	.01259	555	.01304	555	.29518	401	.29604	402	36
37	.01814	551	.01860	552	.29919	399	.30006	400	37
38	.02366	548	.02412	548	.30319	397	.30406	398	38
39	.02914	544	.02960	545	.30716	395	.30804	396	39
40	7.03458	541	7.03505	541	7.31112	393	7.31201	394	40
41	.03999	537	.04047	538	.31505	392	.31595	393	41
42	.04537	534	.04585	535	.31897	390	.31988	391	42
43	.05071	531	.05120	531	.32288	388	.32379	389	43
44	.05603	527	.05652	528	.32676	386	.32768	388	44
45	7.06130	525	7.06180	525	7.33063	385	7.33156	385	45
46	.06655	521	.06706	522	.33448	383	.33542	384	46
47	.07177	518	.07228	519	.33831	382	.33926	382	47
48	.07695	515	.07747	516	.34213	380	.34309	380	48
49	.08211	512	.08263	513	.34593	378	.34689	379	49
50	7.08723	509	7.08776	509	7.34971	377	7.35069	377	50
51	.09232	506	.09286	507	.35348	375	.35446	376	51
52	.09739	503	.09793	503	.35723	373	.35822	374	52
53	.10242	500	.10297	501	.36097	371	.36196	373	53
54	.10743	497	.10798	498	.36468	370	.36569	371	54
55	7.11240	495	7.11297	495	7.36839	368	7.36940	369	55
56	.11735	492	.11792	493	.37207	367	.37310	368	56
57	.12227	489	.12285	490	.37574	366	.37678	366	57
58	.12716	486	.12775	487	.37940	364	.38044	365	58
59	.13203	484	.13262	484	.38304	362	.38409	363	59
60	7.13687		7.13746		7.38667		7.38773		60
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

4°

5°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.		
0	7.38667	361	7.38773	361	7.58039	289	7.58204	290	0			
1	.39028	359	.39134	360	.58328	287	.58494	289	1			
2	.39387	358	.39495	359	.58615	287	.58783	288	2			
3	.39743	356	.39854	357	.58902	286	.59071	287	3		360	350
4	.40102	355	.40211	356	.59188	285	.59358	286	4	6	36.0	35.0
5	7.40457	353	7.40567	354	7.59473	284	7.59645	285	5	7	42.0	40.8
6	.40810	352	.40922	353	.59758	283	.59930	284	6	8	48.0	46.6
7	.41163	350	.41275	352	.60041	282	.60214	283	7	9	54.0	51.5
8	.41513	349	.41627	350	.60323	281	.60498	282	8	10	60.0	58.3
9	.41863	348	.41977	349	.60604	280	.60786	281	9	20	120.0	116.6
10	7.42211	346	7.42326	347	7.60885	279	7.61062	280	10	30	180.0	175.0
11	.42557	345	.42673	346	.61164	279	.61342	280	11	40	240.0	233.3
12	.42903	343	.43019	345	.61443	277	.61622	279	12	50	300.0	291.6
13	.43246	342	.43364	343	.61721	276	.61901	278	13			
14	.43589	341	.43708	342	.61998	275	.62179	277	14	6	33.0	32.0
15	7.43930	339	7.44050	340	7.62274	274	7.62456	276	15	7	38.5	37.3
16	.44270	338	.44390	339	.62549	273	.62733	275	16	8	44.0	42.6
17	.44608	337	.44730	338	.62823	272	.63008	274	17	9	49.5	48.0
18	.44946	335	.45068	337	.63096	271	.63282	273	18	10	55.0	53.3
19	.45281	334	.45405	336	.63369	270	.63556	272	19	20	110.0	106.6
20	7.45616	333	7.45740	334	7.63641	269	7.63829	271	20	30	165.0	160.0
21	.45949	332	.46075	333	.63911	268	.64101	270	21	40	220.0	213.3
22	.46281	330	.46407	332	.64181	267	.64372	269	22	50	275.0	266.6
23	.46612	329	.46739	331	.64451	266	.64643	268	23			
24	.46941	328	.47070	330	.64719	265	.64912	267	24	6	30.0	29.0
25	7.47270	327	7.47399	329	7.64986	264	7.65181	266	25	7	35.0	33.8
26	.47597	325	.47727	328	.65253	263	.65449	265	26	8	40.0	38.6
27	.47922	324	.48054	327	.65519	262	.65716	264	27	9	45.0	43.5
28	.48247	323	.48379	326	.65784	261	.65982	263	28	10	50.0	48.0
29	.48570	322	.48703	325	.66048	260	.66247	262	29	20	100.0	96.6
30	7.48892	321	7.49026	324	7.66311	259	7.66512	261	30	30	150.0	145.0
31	.49213	320	.49348	323	.66574	258	.66776	260	31	40	200.0	193.3
32	.49533	318	.49669	322	.66836	257	.67039	259	32	50	250.0	241.6
33	.49852	317	.49989	321	.67097	256	.67301	258	33			
34	.50169	316	.50307	320	.67357	255	.67562	257	34	6	27.0	26.0
35	7.50485	315	7.50624	319	7.67617	254	7.67823	256	35	7	31.5	30.3
36	.50800	314	.50941	318	.67875	253	.68083	255	36	8	36.0	34.6
37	.51114	313	.51256	317	.68133	252	.68342	254	37	9	40.5	39.0
38	.51427	311	.51569	316	.68390	251	.68601	253	38	10	45.0	43.3
39	.51739	310	.51882	315	.68647	250	.68858	252	39	20	90.0	87.6
40	7.52050	309	7.52194	314	7.68902	249	7.69115	251	40	30	135.0	130.0
41	.52359	308	.52504	313	.69157	248	.69371	250	41	40	180.0	173.3
42	.52667	307	.52814	312	.69411	247	.69627	249	42	50	225.0	216.6
43	.52975	306	.53122	311	.69665	246	.69881	248	43			
44	.53281	305	.53429	310	.69917	245	.70135	247	44	6	24.0	23.0
45	7.53586	304	7.53735	309	7.70169	244	7.70388	246	45	7	28.0	26.8
46	.53890	303	.54041	308	.70421	243	.70641	245	46	8	32.0	30.6
47	.54193	302	.54345	307	.70671	242	.70893	244	47	9	36.0	34.5
48	.54495	301	.54648	306	.70921	241	.71144	243	48	10	40.0	38.3
49	.54796	300	.54950	305	.71170	240	.71394	242	49	20	80.0	76.6
50	7.55096	299	7.55251	304	7.71418	239	7.71644	241	50	30	120.0	115.0
51	.55395	297	.55550	303	.71666	238	.71892	240	51	40	160.0	153.3
52	.55692	296	.55849	302	.71913	237	.72141	239	52	50	200.0	191.6
53	.55989	295	.56147	301	.72159	236	.72388	238	53			
54	.56285	294	.56444	300	.72404	235	.72635	237	54	6	21.0	20.0
55	7.56580	293	7.56740	299	7.72649	234	7.72881	236	55	7	24.5	23.3
56	.56873	292	.57035	298	.72893	233	.73126	235	56	8	28.0	26.8
57	.57166	291	.57329	297	.73137	232	.73371	234	57	9	31.5	30.3
58	.57458	290	.57621	296	.73379	231	.73615	233	58	10	35.0	33.3
59	.57749	289	.57913	295	.73621	230	.73859	232	59	20	70.0	66.6
60	7.58039	288	7.58204	294	7.73863	229	7.74101	231	60	30	105.0	100.0
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D				

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

6°

7°

6°					7°					P. P.			
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D				
0	7.73863	241	7.74101	242	0	7.87238	206	7.87563	208	0			
1	.74104	240	.74343	241	1	.87444	205	.87771	207	1	180	8	9
2	.74344	239	.74585	241	2	.87650	205	.87978	207	2	6	18 0	0.9
3	.74583	239	.74826	240	3	.87855	204	.88185	206	3	7	21.0	1.1
4	.74822	238	.75066	239	4	.88060	204	.88391	206	4	8	24.0	1.2
5	7.75060	237	7.75305	239	5	7.88264	204	7.88597	205	5	9	27.0	1.4
6	.75297	236	.75544	238	6	.88468	203	.88803	205	6	10	30.0	1.6
7	.75534	236	.75782	237	7	.88672	203	.89008	204	7	20	60.0	3.1
8	.75770	235	.76019	237	8	.88875	202	.89212	204	8	30	90.0	4.7
9	.76006	234	.76256	236	9	.89077	202	.89416	203	9	40	120.0	6.3
10	7.76240	234	7.76492	235	10	7.89279	201	7.89620	203	10	50	150.0	7.9
11	.76475	233	.76728	235	11	.89481	201	.89823	202	11			
12	.76708	233	.76963	234	12	.89682	200	.90025	202	12	6	0.8	0.8
13	.76941	232	.77197	233	13	.89882	199	.90228	201	13	7	1.0	0.9
14	.77173	232	.77431	233	14	.90082	199	.90429	201	14	8	1.1	1.0
15	7.77405	231	7.77664	232	15	7.90282	198	7.90630	201	15	9	1.3	1.1
16	.77636	230	.77897	231	16	.90481	198	.90831	200	16	10	1.4	1.2
17	.77867	230	.78128	231	17	.90680	197	.91032	199	17	20	2.8	2.5
18	.78097	229	.78360	230	18	.90878	197	.91231	199	18	30	4.2	3.7
19	.78326	228	.78590	229	19	.91076	197	.91431	198	19	40	5.6	5.0
20	7.78554	228	7.78820	229	20	7.91273	196	7.91630	198	20	50	7.1	6.2
21	.78783	227	.79050	228	21	.91470	196	.91828	197	21			
22	.79010	227	.79279	228	22	.91667	195	.92027	196	22	6	0.7	0.6
23	.79237	226	.79507	227	23	.91863	195	.92224	195	23	7	0.8	0.7
24	.79463	225	.79735	226	24	.92058	194	.92421	194	24	8	0.9	0.8
25	7.79689	225	7.79962	226	25	7.92253	193	7.92618	193	25	9	1.0	0.9
26	.79914	224	.80188	225	26	.92448	193	.92815	192	26	10	1.1	1.0
27	.80138	224	.80414	225	27	.92642	192	.93010	191	27	20	2.3	2.0
28	.80362	223	.80639	224	28	.92836	191	.93206	190	28	30	3.5	3.0
29	.80586	222	.80864	223	29	.93029	190	.93401	189	29	40	4.6	4.0
30	7.80808	222	7.81088	223	30	7.93222	189	7.93596	188	30	50	5.8	5.0
31	.81031	221	.81312	223	31	.93415	188	.93790	187	31			
32	.81252	221	.81535	222	32	.93607	187	.93984	186	32	6	0.5	0.4
33	.81473	220	.81758	221	33	.93799	186	.94177	185	33	7	0.6	0.5
34	.81694	220	.81980	220	34	.93990	185	.94370	184	34	8	0.7	0.6
35	7.81914	219	7.82201	221	35	7.94181	184	7.94562	183	35	9	0.8	0.7
36	.82133	219	.82422	220	36	.94371	183	.94754	182	36	10	0.9	0.8
37	.82352	218	.82642	219	37	.94561	182	.94946	181	37	20	1.8	1.5
38	.82570	217	.82862	218	38	.94751	181	.95137	180	38	30	2.7	2.2
39	.82788	217	.83081	217	39	.94940	180	.95328	179	39	40	3.6	3.0
40	7.83005	217	7.83300	218	40	7.95129	179	7.95519	178	40	50	4.6	3.9
41	.83222	216	.83518	217	41	.95317	178	.95709	177	41			
42	.83438	215	.83735	216	42	.95505	177	.95898	176	42	6	0.4	0.3
43	.83653	215	.83952	215	43	.95693	176	.96088	175	43	7	0.5	0.4
44	.83868	214	.84169	214	44	.95880	175	.96276	174	44	8	0.6	0.5
45	7.84083	214	7.84385	215	45	7.96066	174	7.96465	173	45	9	0.7	0.6
46	.84297	213	.84600	214	46	.96253	173	.96653	172	46	10	0.8	0.7
47	.84510	213	.84815	213	47	.96439	172	.96841	171	47	20	1.6	1.3
48	.84723	212	.85030	212	48	.96624	171	.97028	170	48	30	2.5	2.0
49	.84935	212	.85243	211	49	.96809	170	.97215	169	49	40	3.4	2.8
50	7.85147	211	7.85457	213	50	7.96994	169	7.97401	168	50	50	4.3	3.7
51	.85359	211	.85670	212	51	.97178	168	.97587	167	51			
52	.85570	210	.85882	211	52	.97362	167	.97773	166	52	6	0.3	0.2
53	.85780	210	.86094	210	53	.97546	166	.97958	165	53	7	0.4	0.3
54	.85990	209	.86305	209	54	.97729	165	.98143	164	54	8	0.5	0.4
55	7.86199	209	7.86516	210	55	7.97912	164	7.98327	163	55	9	0.6	0.5
56	.86408	208	.86726	209	56	.98094	163	.98512	162	56	10	0.7	0.6
57	.86616	208	.86936	208	57	.98276	162	.98695	161	57	20	1.5	1.1
58	.86824	207	.87146	207	58	.98458	161	.98879	160	58	30	2.4	1.9
59	.87031	206	.87354	206	59	.98639	160	.99062	159	59	40	3.3	2.7
60	7.87238		7.87563		60	7.98820		7.99244		60	50	4.2	3.6
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D				

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

8°

9°

Log. Vers.				Log. Exec.				P. P.			
0	7.98820	180	7.99244	182	8.09031	160	8.09569	162	0		
1	.99000	180	.99427	182	.09192	160	.09732	162	1		
2	.99180	179	.99609	181	.09352	160	.09894	162	2		
3	.99360	179	.99790	181	.09512	159	.10056	161	3	180	170
4	.99539	179	7.99971	180	.09671	159	.10217	161	4	6	18.0
5	7.99718	178	8.00152	180	8.09830	159	8.10378	161	5	7	21.0
6	7.99897	178	.00332	180	.09989	158	.10539	160	6	8	24.0
7	8.00073	177	.00512	180	.10148	158	.10700	160	7	9	27.0
8	.00253	178	.00692	179	.10306	158	.10860	160	8	10	30.0
9	.00431	177	.00871	179	.10464	157	.11020	160	9	20	60.0
10	8.00608	176	8.01050	178	8.10622	157	8.11180	159	10	30	90.0
11	.00784	176	.01229	178	.10779	157	.11340	159	11	40	120.0
12	.00961	176	.01407	178	.10936	157	.11499	159	12	50	150.0
13	.01137	176	.01583	177	.11093	156	.11658	158	13		
14	.01313	175	.01763	177	.11250	156	.11816	158	14	6	15.0
15	8.01488	175	8.01940	177	8.11406	156	8.11975	158	15	7	17.5
16	.01663	175	.02117	176	.11562	155	.12133	158	16	8	20.0
17	.01838	174	.02293	176	.11718	155	.12291	157	17	9	22.5
18	.02012	174	.02469	175	.11873	155	.12448	157	18	10	25.0
19	.02186	173	.02645	175	.12029	155	.12603	157	19	20	50.0
20	8.02359	173	8.02820	175	8.12184	154	8.12762	157	20	30	75.0
21	.02533	173	.02993	175	.12338	154	.12919	156	21	40	100.0
22	.02706	172	.03170	174	.12492	154	.13073	156	22	50	125.0
23	.02878	172	.03345	174	.12647	153	.13232	155	23		
24	.03050	172	.03519	173	.12800	153	.13387	156	24	6	15.0
25	8.03222	171	8.03692	173	8.12954	153	8.13543	155	25	7	17.5
26	.03394	171	.03866	173	.13107	153	.13698	155	26	8	20.0
27	.03565	171	.04039	173	.13260	152	.13854	154	27	9	22.5
28	.03736	170	.04212	172	.13413	152	.14008	154	28	10	25.0
29	.03906	170	.04384	172	.13563	152	.14163	154	29	20	50.0
30	8.04076	170	8.04556	171	8.13717	152	8.14317	154	30	30	75.0
31	.04246	169	.04728	171	.13869	151	.14471	153	31	40	100.0
32	.04416	169	.04899	171	.14021	151	.14625	153	32	50	125.0
33	.04585	169	.05070	170	.14172	151	.14778	153	33		
34	.04754	168	.05241	170	.14323	151	.14932	153	34	6	15.0
35	8.04922	168	8.05411	170	8.14474	150	8.15085	152	35	7	17.5
36	.05090	168	.05581	170	.14625	150	.15237	152	36	8	20.0
37	.05258	167	.05751	169	.14775	150	.15390	152	37	9	22.5
38	.05426	167	.05921	169	.14923	149	.15542	152	38	10	25.0
39	.05593	167	.06090	169	.15075	150	.15694	152	39	20	50.0
40	8.05760	166	8.06259	168	8.15225	149	8.15846	151	40	30	75.0
41	.05926	166	.06427	168	.15374	149	.15997	151	41	40	100.0
42	.06093	166	.06593	168	.15523	149	.16148	151	42	50	125.0
43	.06259	165	.06763	167	.15672	148	.16299	150	43		
44	.06424	165	.06931	167	.15820	148	.16450	150	44	6	15.0
45	8.06589	165	8.07098	167	8.15958	148	8.16600	150	45	7	17.5
46	.06754	165	.07265	166	.16116	148	.16750	150	46	8	20.0
47	.06919	164	.07431	166	.16264	147	.16900	149	47	9	22.5
48	.07083	164	.07598	166	.16412	147	.17050	149	48	10	25.0
49	.07247	164	.07764	165	.16559	147	.17199	149	49	20	50.0
50	8.07411	163	8.07929	165	8.16706	146	8.17349	148	50	30	75.0
51	.07575	163	.08095	165	.16852	146	.17497	148	51	40	100.0
52	.07738	162	.08260	164	.16999	146	.17646	148	52	50	125.0
53	.07900	162	.08424	164	.17143	146	.17795	148	53		
54	.08063	162	.08589	164	.17291	145	.17943	148	54	6	15.0
55	8.08223	161	8.08753	163	8.17437	145	8.18091	147	55	7	17.5
56	.08387	162	.08917	164	.17582	145	.18238	147	56	8	20.0
57	.08549	161	.09081	163	.17728	145	.18386	147	57	9	22.5
58	.08710	161	.09244	163	.17873	144	.18533	147	58	10	25.0
59	.08871	160	.09407	162	.18017	144	.18680	146	59	20	50.0
60	8.09031		8.09569		8.18162		8.18827		60	30	75.0
	Log. Vers.	D	Log. Exec.	D	Log. Vers.	D	Log. Exec.	D		P. P.	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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11°

	Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D		P. P.
0	8.18162	144	8.18827	146	8.26417	131	8.27223	133	0	
1	.18306	144	.18973	146	.26548	131	.27356	133	1	
2	.18450	144	.19120	146	.26679	131	.27490	133	2	
3	.18594	144	.19266	146	.26810	131	.27623	133	3	
4	.18738	143	.19411	145	.26941	130	.27756	133	4	
5	8.18881	143	8.19557	145	8.27071	130	8.27889	132	5	
6	.19024	142	.19702	145	.27201	130	.28021	132	6	130 120
7	.19167	142	.19847	145	.27331	130	.28153	132	7	13.0 12.0
8	.19309	142	.19992	145	.27461	130	.28286	132	8	15.0 14.0
9	.19452	142	.20137	144	.27596	129	.28418	132	9	17.3 16.0
10	8.19594	142	8.20281	144	8.27719	129	8.28550	132	10	19.5 18.0
11	.19736	142	.20425	144	.27849	128	.28681	131	11	21.6 20.0
12	.19878	141	.20569	144	.27977	128	.28813	131	12	23.3 22.0
13	.20019	141	.20713	143	.28106	128	.28944	131	13	25.0 24.0
14	.20160	141	.20857	143	.28235	128	.29075	131	14	26.5 25.0
15	8.20301	140	8.21000	143	8.28363	128	8.29206	130	15	
16	.20442	140	.21143	143	.28491	128	.29336	130	16	28.0 27.0
17	.20582	140	.21286	142	.28619	128	.29467	130	17	29.5 28.0
18	.20723	140	.21428	142	.28747	127	.29597	130	18	31.0 29.0
19	.20863	140	.21571	142	.28875	127	.29727	130	19	32.5 30.0
20	8.21003	139	8.21713	142	8.29002	127	8.29857	130	20	
21	.21142	139	.21855	141	.29129	127	.29987	129	21	34.0 32.0
22	.21282	139	.21996	141	.29256	127	.30117	129	22	35.5 33.0
23	.21421	139	.22138	141	.29383	126	.30246	129	23	37.0 34.0
24	.21560	138	.22279	141	.29510	126	.30375	129	24	38.5 35.0
25	8.21698	138	8.22420	140	8.29636	126	8.30504	129	25	
26	.21837	138	.22561	140	.29763	126	.30633	129	26	40.0 38.0
27	.21975	138	.22701	140	.29889	126	.30762	128	27	41.5 39.0
28	.22113	138	.22842	140	.30015	125	.30890	128	28	43.0 40.0
29	.22251	137	.22982	140	.30146	125	.31019	128	29	44.5 41.0
30	8.22389	137	8.23122	140	8.30266	125	8.31147	128	30	
31	.22526	137	.23262	139	.30391	125	.31275	127	31	46.0 42.0
32	.22663	137	.23401	139	.30516	125	.31402	127	32	47.5 43.0
33	.22800	136	.23540	139	.30642	124	.31530	127	33	49.0 44.0
34	.22937	136	.23679	139	.30768	124	.31657	127	34	50.5 45.0
35	8.23073	136	8.23818	138	8.30891	124	8.31785	127	35	
36	.23209	136	.23957	138	.31015	124	.31912	127	36	52.0 46.0
37	.23346	135	.24095	138	.31140	124	.32039	126	37	53.5 47.0
38	.23481	136	.24234	138	.31264	124	.32165	126	38	55.0 48.0
39	.23617	135	.24372	137	.31388	123	.32292	126	39	56.5 49.0
40	8.23752	135	8.24509	138	8.31511	124	8.32418	126	40	
41	.23888	135	.24647	137	.31635	123	.32544	126	41	58.0 50.0
42	.24023	135	.24784	137	.31758	123	.32670	126	42	59.5 51.0
43	.24158	134	.24922	137	.31882	123	.32796	125	43	61.0 52.0
44	.24292	134	.25059	136	.32005	123	.32922	125	44	62.5 53.0
45	8.24426	134	8.25195	136	8.32128	122	8.33047	125	45	
46	.24561	134	.25332	136	.32250	122	.33173	125	46	64.0 54.0
47	.24695	133	.25468	136	.32373	122	.33298	125	47	65.5 55.0
48	.24829	133	.25604	136	.32495	122	.33423	124	48	67.0 56.0
49	.24963	133	.25740	136	.32617	122	.33547	124	49	68.5 57.0
50	8.25097	133	8.25876	135	8.32739	122	8.33672	124	50	
51	.25231	133	.26012	135	.32861	121	.33797	124	51	70.0 58.0
52	.25365	132	.26147	135	.32983	121	.33921	124	52	71.5 59.0
53	.25499	133	.26282	135	.33104	121	.34045	123	53	73.0 60.0
54	.25632	132	.26417	134	.33225	121	.34169	124	54	74.5 61.0
55	8.25766	132	8.26552	134	8.33347	121	8.34293	124	55	
56	.25899	132	.26686	134	.33468	120	.34417	123	56	76.0 62.0
57	.26033	132	.26821	134	.33588	120	.34540	123	57	77.5 63.0
58	.26167	131	.26955	134	.33709	120	.34663	123	58	79.0 64.0
59	.26300	131	.27089	134	.33829	120	.34786	123	59	80.5 65.0
60	8.26417		8.27223		8.33950		8.34909		60	
	Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D		P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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13°

												P. P.			
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D						
0	8.33950	120	8.34909	123	8.40875	110		8.42002	113	0					
1	.34070	120	.35032	122	.40985	110		.42116	113	1					
2	.34190	119	.35155	122	.41096	110		.42229	113	2					
3	.34309	120	.35277	122	.41206	110		.42343	113	3		120	119	118	
4	.34429	119	.35399	122	.41317	110		.42456	113	4	6	12.0	11.9	11.8	
5	8.34549	119	8.35522	122	8.41427	110		8.42569	113	5	7	14.0	13.9	13.7	
6	.34668	119	.35644	121	.41537	110		.42682	113	6	8	16.0	15.8	15.7	
7	.34787	119	.35765	122	.41647	110		.42795	113	7	9	18.0	17.8	17.7	
8	.34906	119	.35887	121	.41757	109		.42908	113	8	10	20.0	19.8	19.7	
9	.35025	118	.36009	121	.41867	110		.43021	112	9	20	40.0	39.6	39.5	
10	8.35143	118	8.36130	121	8.41976	109		8.43133	112	10	30	60.0	59.5	59.4	
11	.35262	118	.36251	121	.42086	109		.43246	112	11	40	80.0	79.3	78.9	
12	.35380	118	.36372	120	.42195	109		.43358	112	12	50	100.0	99.1	98.3	
13	.35498	118	.36493	121	.42304	109		.43470	112	13					
14	.35616	117	.36614	120	.42413	109		.43582	112	14	6	11.7	11.6	11.5	
15	8.35734	118	8.36734	120	8.42522	108		8.43694	111	15	7	13.6	13.5	13.4	
16	.35852	117	.36855	120	.42630	109		.43805	111	16	8	15.6	15.4	15.3	
17	.35969	117	.36975	120	.42739	108		.43917	111	17	9	17.5	17.4	17.3	
18	.36086	117	.37095	120	.42847	108		.44028	111	18	10	19.5	19.3	19.1	
19	.36204	117	.37215	120	.42956	108		.44139	111	19	20	39.0	38.6	38.5	
20	8.36321	116	8.37335	119	8.43064	108		8.44251	111	20	30	58.5	58.0	57.9	
21	.36437	117	.37454	119	.43172	108		.44362	111	21	40	78.0	77.3	76.7	
22	.36554	116	.37574	119	.43280	108		.44473	110	22	50	97.5	96.6	95.5	
23	.36671	116	.37693	119	.43388	107		.44583	110	23					
24	.36787	116	.37812	119	.43495	107		.44694	110	24	6	11.4	11.3	11.2	
25	8.36903	116	8.37931	118	8.43603	107		8.44804	110	25	7	13.3	13.2	13.1	
26	.37019	116	.38050	119	.43710	107		.44915	110	26	8	15.2	15.0	14.9	
27	.37135	115	.38169	118	.43817	107		.45025	110	27	9	17.1	16.0	15.8	
28	.37251	115	.38287	118	.43924	107		.45135	110	28	10	19.0	18.8	18.7	
29	.37366	115	.38406	118	.44031	107		.45245	109	29	20	38.0	37.6	37.5	
30	8.37482	115	8.38524	118	8.44138	106		8.45355	110	30	30	57.0	56.5	56.4	
31	.37597	115	.38642	118	.44245	106		.45465	110	31	40	76.0	75.3	74.7	
32	.37712	115	.38760	118	.44351	106		.45574	109	32	50	95.0	94.1	93.3	
33	.37827	115	.38878	117	.44458	106		.45684	109	33					
34	.37942	114	.38995	117	.44564	106		.45793	109	34	6	11.1	11.0	10.9	
35	8.38057	114	8.39113	117	8.44670	106		8.45902	109	35	7	12.9	12.8	12.7	
36	.38171	114	.39230	117	.44776	105		.46011	109	36	8	14.8	14.6	14.5	
37	.38286	114	.39347	117	.44882	106		.46120	108	37	9	16.6	16.5	16.4	
38	.38400	114	.39464	117	.44988	105		.46229	108	38	10	18.5	18.3	18.1	
39	.38514	114	.39581	116	.45093	105		.46338	108	39	20	37.0	36.6	36.5	
40	8.38628	113	8.39698	116	8.45199	105		8.46446	108	40	30	55.5	55.0	54.9	
41	.38741	114	.39814	116	.45304	105		.46555	108	41	40	74.0	73.3	72.7	
42	.38855	113	.39931	116	.45409	105		.46663	108	42	50	92.5	91.6	90.8	
43	.38969	113	.40047	116	.45514	105		.46771	108	43					
44	.39082	113	.40163	116	.45619	105		.46879	108	44	6	10.8	10.7	10.6	
45	8.39195	113	8.40279	116	8.45724	104		8.46987	107	45	7	12.6	12.5	12.4	
46	.39308	113	.40395	115	.45829	105		.47095	108	46	8	14.4	14.2	14.1	
47	.39421	113	.40511	115	.45934	105		.47203	107	47	9	16.2	16.0	15.9	
48	.39534	112	.40626	115	.46038	104		.47310	107	48	10	18.0	17.8	17.7	
49	.39646	112	.40742	115	.46142	104		.47417	107	49	20	36.0	35.6	35.5	
50	8.39758	112	8.40857	115	8.46247	104		8.47525	107	50	30	54.0	53.5	53.4	
51	.39871	112	.40972	115	.46351	104		.47632	107	51	40	72.0	71.3	70.7	
52	.39983	112	.41087	115	.46455	103		.47739	106	52	50	90.0	89.1	88.3	
53	.40095	112	.41202	114	.46558	103		.47846	106	53					
54	.40207	111	.41317	114	.46662	103		.47953	107	54	6	10.5	10.4	0.0	
55	8.40318	111	8.41431	114	8.46766	103		8.48060	106	55	7	12.2	12.1	0.0	
56	.40430	111	.41546	114	.46869	103		.48166	106	56	8	14.0	13.8	0.0	
57	.40541	111	.41660	114	.46972	103		.48273	106	57	9	15.7	15.6	0.1	
58	.40652	111	.41774	114	.47076	103		.48379	106	58	10	17.5	17.3	0.1	
59	.40764	111	.41888	114	.47179	103		.48485	106	59	20	35.0	34.6	0.2	
60	8.40875		8.42002		8.47282			8.48591		60	30	52.5	52.0	0.3	
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D				P. P.			

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

14°

15°

14°					15°					P. P.			
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D				
0	8.47282	102	8.48591	106	8.53242	96	8.54748	99	0				
1	.47384	103	.48697	106	.53338	95	.54847	99	1				
2	.47487	102	.48803	105	.53434	96	.54946	99	2				
3	.47590	102	.48909	105	.53530	95	.55045	99	3				
4	.47692	102	.49014	105	.53625	95	.55144	99	4				
5	8.47795	102	8.49120	105	8.53721	95	8.55243	99	5	6	103	102	101
6	.47897	102	.49225	105	.53816	95	.55342	99	6	7	10.3	10.2	10.1
7	.47999	102	.49331	105	.53911	95	.55441	98	7	8	12.0	11.9	11.8
8	.48101	102	.49436	105	.54007	95	.55539	98	8	9	13.7	13.6	13.4
9	.48203	101	.49541	105	.54102	95	.55638	98	9	10	15.4	15.3	15.1
10	8.48304	101	8.49646	104	8.54197	94	8.55736	98	10	20	17.1	17.0	16.8
11	.48406	101	.49750	104	.54291	95	.55834	98	11	30	34.3	34.0	33.6
12	.48507	101	.49855	104	.54386	94	.55933	98	12	40	51.5	51.0	50.5
13	.48609	101	.49960	104	.54481	94	.56031	98	13	50	68.6	68.0	67.3
14	.48710	101	.50064	104	.54575	94	.56129	97	14		85.8	85.0	84.1
15	8.48811	101	8.50168	104	8.54670	94	8.56226	98	15				
16	.48912	101	.50273	104	.54764	94	.56324	97	16	6	100	99	98
17	.49013	100	.50377	104	.54858	94	.56422	97	17	7	10.0	9.9	9.8
18	.49114	101	.50481	104	.54952	94	.56519	97	18	8	11.6	11.5	11.4
19	.49215	100	.50585	103	.55046	94	.56617	97	19	9	13.3	13.2	13.0
20	8.49315	100	8.50688	104	8.55140	93	8.56714	97	20	10	15.0	14.8	14.7
21	.49415	100	.50792	103	.55234	94	.56812	97	21	20	16.6	16.5	16.3
22	.49516	100	.50896	103	.55328	93	.56909	97	22	30	33.3	33.0	32.6
23	.49616	100	.50999	103	.55421	93	.57006	97	23	40	50.0	49.5	49.0
24	.49716	100	.51102	103	.55515	93	.57103	97	24	50	66.6	66.0	65.3
25	8.49816	100	8.51205	103	8.55608	93	8.57200	97	25		83.3	82.5	81.6
26	.49916	99	.51309	103	.55701	93	.57296	96	26				
27	.50015	100	.51412	102	.55795	93	.57393	96	27				
28	.50115	99	.51514	103	.55888	93	.57490	96	28	6	97	96	95
29	.50215	99	.51617	102	.55981	93	.57586	96	29	7	9.7	9.6	9.5
30	8.50314	99	8.51720	102	8.56074	92	8.57682	96	30	8	11.3	11.2	11.1
31	.50413	99	.51822	102	.56166	92	.57779	96	31	9	12.9	12.8	12.6
32	.50512	99	.51925	102	.56259	92	.57875	96	32	10	14.5	14.4	14.2
33	.50611	99	.52027	102	.56352	92	.57971	96	33	20	16.1	16.0	15.8
34	.50710	98	.52129	102	.56444	92	.58067	95	34	30	32.3	32.0	31.6
35	8.50809	99	8.52231	102	8.56536	92	8.58163	95	35	40	48.5	48.0	47.5
36	.50908	98	.52333	102	.56629	92	.58259	95	36	50	64.6	64.0	63.3
37	.51006	98	.52435	101	.56721	92	.58354	95	37		80.8	80.0	79.1
38	.51105	98	.52537	101	.56813	92	.58450	95	38				
39	.51203	98	.52638	101	.56905	92	.58546	95	39				
40	8.51301	98	8.52740	101	8.56997	92	8.58641	95	40	6	94	93	92
41	.51399	98	.52841	101	.57089	91	.58736	95	41	7	9.4	9.3	9.2
42	.51497	98	.52943	101	.57180	91	.58832	95	42	8	10.9	10.8	10.7
43	.51595	97	.53044	101	.57272	91	.58927	95	43	9	12.5	12.4	12.2
44	.51693	98	.53145	101	.57363	91	.59022	95	44	10	14.1	13.9	13.8
45	8.51791	97	8.53246	101	8.57455	91	8.59117	95	45	20	15.6	15.5	15.3
46	.51888	97	.53347	101	.57546	91	.59211	94	46	30	31.3	31.0	30.6
47	.51986	97	.53448	100	.57637	91	.59306	94	47	40	47.0	46.5	46.0
48	.52083	97	.53548	100	.57728	91	.59401	94	48	50	62.6	62.0	61.3
49	.52180	97	.53649	100	.57819	91	.59495	94	49		78.3	77.5	76.6
50	8.52277	97	8.53749	100	8.57910	90	8.59590	94	50				
51	.52374	97	.53850	100	.58001	90	.59684	94	51	6	91	90	8
52	.52471	96	.53950	100	.58092	90	.59779	94	52	7	9.1	9.0	0.6
53	.52568	97	.54050	100	.58182	90	.59873	94	53	8	10.6	10.5	0.6
54	.52665	96	.54150	100	.58273	90	.59967	94	54	9	12.1	12.0	0.6
55	8.52761	96	8.54250	100	8.58363	90	8.60061	94	55	10	13.6	13.5	0.1
56	.52858	96	.54350	99	.58453	90	.60155	94	56	20	15.1	15.0	0.1
57	.52954	96	.54449	99	.58544	90	.60249	93	57	30	30.3	30.0	0.1
58	.53050	96	.54549	99	.58634	90	.60342	94	58	40	45.5	45.0	0.2
59	.53146	96	.54649	99	.58724	90	.60436	93	59	50	60.6	60.0	0.3
60	8.53242		8.54748		8.58814		8.60530		60		75.8	75.0	0.4
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D			P. P.		

16°

17°

Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.		
8.58814	90	8.60530	93	8.64043	84	8.65984	88	0			
.58904	89	.60623	93	.64128	84	.66072	88	1			
.58993	89	.60716	93	.64212	84	.66160	88	2			
.59083	89	.60810	93	.64296	84	.66248	88	3			
.59173	89	.60903	93	.64381	84	.66336	88	4			
8.59262	89	8.60996	93	8.64465	84	8.66425	88	5			
.59351	89	.61089	93	.64549	84	.66512	88	6			
.59441	89	.61182	93	.64633	84	.66600	88	7			
.59530	89	.61275	92	.64717	84	.66688	88	8			
.59619	89	.61368	93	.64801	84	.66776	87	9			
8.59708	89	8.61460	92	8.64884	83	8.66863	87	10			
.59797	89	.61553	92	.64968	83	.66951	88	11			
.59886	89	.61645	92	.65052	84	.67039	87	12			
.59974	88	.61738	92	.65135	83	.67126	87	13			
.60063	89	.61830	92	.65218	83	.67213	87	14			
8.60152	88	8.61922	92	8.65302	83	8.67301	87	15			
.60240	88	.62014	92	.65385	83	.67388	87	16			
.60328	88	.62106	92	.65468	83	.67475	87	17			
.60417	88	.62198	92	.65551	83	.67562	87	18			
.60505	88	.62290	92	.65634	83	.67649	87	19			
8.60593	88	8.62382	91	8.65717	83	8.67736	87	20			
.60681	88	.62474	92	.65800	83	.67822	86	21			
.60769	88	.62565	91	.65883	82	.67909	87	22			
.60857	88	.62657	91	.65965	82	.67996	86	23			
.60944	87	.62748	91	.66048	83	.68082	86	24			
8.61032	87	8.62840	91	8.66131	82	8.68169	86	25			
.61119	87	.62931	91	.66213	82	.68255	86	26			
.61207	87	.63022	91	.66295	82	.68341	86	27			
.61294	87	.63113	91	.66378	82	.68428	86	28			
.61381	87	.63204	91	.66460	82	.68514	86	29			
8.61469	87	8.63295	90	8.66542	82	8.68600	86	30			
.61556	87	.63386	91	.66624	82	.68686	86	31			
.61643	87	.63477	91	.66706	82	.68772	86	32			
.61730	86	.63567	90	.66788	82	.68858	86	33			
.61816	86	.63658	90	.66870	82	.68944	86	34			
8.61903	87	8.63748	90	8.66951	81	8.69029	85	35			
.61990	86	.63839	90	.67033	81	.69115	86	36			
.62076	86	.63929	90	.67115	82	.69201	85	37			
.62163	86	.64019	90	.67196	81	.69286	85	38			
.62249	86	.64109	90	.67277	81	.69372	85	39			
8.62336	86	8.64199	90	8.67359	81	8.69457	85	40			
.62422	86	.64289	90	.67440	81	.69542	85	41			
.62508	86	.64379	90	.67521	81	.69627	85	42			
.62594	86	.64469	90	.67602	81	.69712	85	43			
.62680	86	.64559	89	.67683	81	.69798	85	44			
8.62766	86	8.64649	90	8.67764	81	8.69883	85	45			
.62852	86	.64738	89	.67845	81	.69967	84	46			
.62937	85	.64828	89	.67926	80	.70052	85	47			
.63023	85	.64917	89	.68007	81	.70137	85	48			
.63108	85	.65006	89	.68087	80	.70222	84	49			
8.63194	85	8.65096	89	8.68168	80	8.70306	84	50			
.63279	85	.65185	89	.68248	80	.70391	84	51			
.63364	85	.65274	89	.68329	80	.70475	84	52			
.63449	85	.65363	89	.68409	80	.70560	84	53			
.63534	85	.65452	89	.68489	80	.70644	84	54			
8.63619	85	8.65541	89	8.68569	80	8.70728	84	55			
.63704	85	.65629	88	.68650	80	.70813	84	56			
.63789	85	.65718	88	.68730	80	.70897	84	57			
.63874	84	.65807	89	.68810	80	.70981	84	58			
.63959	85	.65895	88	.68889	79	.71065	84	59			
8.64043	84	8.65984	88	8.68969	80	8.71149	84	60			
Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.		

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

18°

19°

		Log. Vers.	D	Log. Exsec.			Log. Vers.	D	Log. Exsec.			P. P.		
0	8.68969	79	8.71149	83	8.73625	75	8.76058	79	0					
1	.69049	80	.71232	84	.73700	75	.76137	80	1					
2	.69129	79	.71316	83	.73775	75	.76217	79	2					
3	.69208	79	.71400	84	.73851	75	.76297	79	3					
4	.69288	79	.71484	83	.73926	75	.76376	80	4					
5	8.69367	79	8.71567	83	8.74001	75	8.76456	79	5	6	84	83	82	
6	.69446	79	.71651	83	.74076	75	.76536	79	6	7	8.4	8.3	8.2	
7	.69526	79	.71734	83	.74151	75	.76615	79	7	8	9.8	9.7	9.5	
8	.69605	79	.71817	83	.74226	75	.76694	79	8	9	11.2	11.0	10.9	
9	.69684	79	.71901	83	.74301	75	.76774	79	9	10	12.6	12.4	12.3	
10	8.69763	79	8.71984	83	8.74376	75	8.76853	79	10	20	14.0	13.8	13.6	
11	.69842	79	.72067	83	.74451	74	.76932	79	11	30	28.0	27.6	27.3	
12	.69921	79	.72150	83	.74526	75	.77011	79	12	40	42.0	41.5	41.0	
13	.70000	78	.72233	83	.74600	74	.77090	79	13	50	56.0	55.3	54.6	
14	.70079	79	.72316	83	.74675	74	.77169	79	14		70.0	69.1	68.3	
15	8.70157	78	8.72399	82	8.74749	74	8.77248	79	15					
16	.70236	78	.72481	83	.74824	74	.77327	79	16	6	81	80	79	
17	.70314	78	.72564	82	.74898	74	.77406	78	17	7	8.1	8.0	7.9	
18	.70393	78	.72647	82	.74973	74	.77485	79	18	8	9.4	9.3	9.2	
19	.70471	78	.72729	82	.75047	74	.77563	78	19	9	10.8	10.6	10.5	
20	8.70550	78	8.72812	82	8.75121	74	8.77642	78	20	10	12.1	12.0	11.8	
21	.70628	78	.72894	82	.75195	74	.77720	78	21	20	13.5	13.3	13.1	
22	.70706	78	.72977	82	.75269	74	.77799	79	22	30	27.0	26.6	26.3	
23	.70784	78	.73059	82	.75343	74	.77877	78	23	40	40.5	40.0	39.5	
24	.70862	78	.73141	82	.75417	74	.77956	78	24	50	54.0	53.3	52.6	
25	8.70940	78	8.73223	82	8.75491	74	8.78034	78	25		67.5	66.6	65.3	
26	.71018	77	.73306	82	.75565	73	.78112	78	26					
27	.71096	77	.73388	82	.75639	73	.78191	78	27	6	78	77	76	
28	.71174	77	.73470	81	.75712	73	.78269	78	28	7	7.8	7.7	7.6	
29	.71251	77	.73551	82	.75786	73	.78347	78	29	8	9.1	9.0	8.8	
30	8.71329	77	8.73633	82	8.75860	74	8.78425	78	30	9	10.4	10.2	10.1	
31	.71406	77	.73715	81	.75933	73	.78503	78	31	10	11.7	11.5	11.4	
32	.71484	77	.73797	81	.76006	74	.78581	78	32	20	13.0	12.8	12.6	
33	.71561	77	.73878	81	.76080	73	.78659	78	33	30	26.0	25.6	25.3	
34	.71639	77	.73960	81	.76153	73	.78736	77	34	40	39.0	38.5	38.0	
35	8.71716	77	8.74041	81	8.76226	73	8.78814	78	35	50	52.0	51.3	50.6	
36	.71793	77	.74123	81	.76300	73	.78892	77	36		65.0	64.1	63.3	
37	.71870	77	.74204	81	.76373	73	.78969	77	37					
38	.71947	77	.74286	81	.76446	73	.79047	77	38	6	75	74	73	
39	.72024	77	.74367	81	.76519	73	.79124	77	39	7	7.5	7.4	7.3	
40	8.72101	76	8.74448	81	8.76592	72	8.79202	77	40	8	8.7	8.6	8.5	
41	.72178	77	.74529	81	.76664	72	.79279	77	41	9	10.0	9.8	9.7	
42	.72255	76	.74610	81	.76737	72	.79357	77	42	10	11.2	11.1	10.9	
43	.72331	77	.74691	80	.76810	72	.79434	77	43	20	12.5	12.3	12.1	
44	.72408	76	.74772	81	.76883	72	.79511	77	44	30	25.0	24.6	24.3	
45	8.72485	76	8.74853	81	8.76955	72	8.79588	77	45	40	37.5	37.0	36.5	
46	.72561	76	.74934	80	.77028	72	.79665	77	46	50	50.0	49.3	48.6	
47	.72637	76	.75014	80	.77100	72	.79742	77	47		62.5	61.6	60.8	
48	.72714	76	.75095	80	.77173	72	.79819	77	48					
49	.72790	76	.75175	80	.77245	72	.79896	77	49	6	72	71	70	
50	8.72866	76	8.75256	80	8.77317	72	8.79973	76	50	7	7.2	7.1	7.0	
51	.72942	76	.75336	80	.77390	72	.80050	77	51	8	8.4	8.3	8.2	
52	.73018	76	.75417	80	.77462	72	.80126	76	52	9	9.6	9.4	9.3	
53	.73094	76	.75497	80	.77534	72	.80203	77	53	10	10.8	10.6	10.5	
54	.73170	76	.75577	80	.77606	72	.80280	76	54	20	12.0	11.8	11.7	
55	8.73246	76	8.75658	80	8.77678	72	8.80356	76	55	30	24.0	23.6	23.3	
56	.73322	75	.75738	80	.77750	72	.80433	76	56	40	36.0	35.5	35.2	
57	.73398	75	.75818	80	.77822	71	.80509	76	57	50	48.0	47.3	46.6	
58	.73473	76	.75898	80	.77893	72	.80586	76	58		60.0	59.1	58.3	
59	.73549	75	.75978	80	.77965	71	.80662	76	59					
60	8.73625		8.76058		8.78037		8.80738		60					
		Log. Vers.	D	Log. Exsec.			Log. Vers.	D	Log. Exsec.			P. P.		

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

20°

21°

												P. P.			
Log. Vers.		D	Log. Exsec.	D	Log. Vers.		D	Log. Exsec.	D						
0	8.78037	71	8.80738	76	8.82229	68	8.85214	73	0						
1	.78108	71	.80814	76	.82297	68	.85287	73	1						
2	.78180	71	.80891	76	.82366	68	.85360	72	2						
3	.78251	71	.80967	76	.82434	68	.85433	72	3						
4	.78323	71	.81043	76	.82502	68	.85506	73	4						
5	8.78394	71	8.81119	76	8.82569	69	8.85579	73	5			76		75	
6	.78466	71	.81195	76	.82637	68	.85651	72	6			7.6		7.5	
7	.78537	71	.81271	76	.82705	68	.85724	73	7			8.8		8.7	
8	.78608	71	.81346	75	.82773	69	.85797	72	8			10.1		10.0	
9	.78679	71	.81422	76	.82841	68	.85869	72	9			11.4		11.2	
10	8.78750	71	8.81498	75	8.82908	69	8.85942	72	10			12.6		12.5	
11	.78821	71	.81573	75	.82976	69	.86014	72	11			25.3		25.0	
12	.78892	71	.81649	76	.83043	69	.86087	72	12			38.0		37.5	
13	.78963	71	.81725	75	.83111	69	.86159	72	13			50.6		50.0	
14	.79034	70	.81800	75	.83178	69	.86231	72	14			63.3		62.5	
15	8.79105	70	8.81876	75	8.83246	69	8.86304	72	15						
16	.79175	70	.81951	75	.83313	67	.86376	72	16			73		72	
17	.79246	70	.82026	75	.83380	69	.86448	72	17			7.3		7.2	
18	.79317	70	.82102	75	.83447	67	.86520	72	18			8.5		8.4	
19	.79387	70	.82177	75	.83515	69	.86592	72	19			9.7		9.6	
20	8.79458	70	8.82252	75	8.83582	67	8.86664	72	20			10.9		10.8	
21	.79528	70	.82327	75	.83649	67	.86736	72	21			12.1		12.0	
22	.79598	70	.82402	75	.83716	67	.86808	72	22			24.3		24.0	
23	.79669	70	.82477	74	.83783	67	.86880	72	23			36.5		36.0	
24	.79739	70	.82552	74	.83850	67	.86952	71	24			48.6		48.0	
25	8.79809	70	8.82627	75	8.83916	66	8.87024	72	25			60.8		60.0	
26	.79879	70	.82702	75	.83983	67	.87095	71	26						
27	.79949	70	.82776	74	.84050	66	.87167	72	27			70		69	
28	.80019	70	.82851	75	.84117	67	.87239	71	28			7.0		6.9	
29	.80089	70	.82926	74	.84183	66	.87310	71	29			8.1		8.0	
30	8.80159	70	8.83000	74	8.84250	66	8.87382	71	30			9.3		9.2	
31	.80229	69	.83075	74	.84316	66	.87453	71	31			10.5		10.3	
32	.80299	69	.83149	74	.84383	66	.87525	71	32			11.6		11.5	
33	.80369	69	.83224	74	.84449	66	.87596	71	33			23.3		23.0	
34	.80438	69	.83298	74	.84515	66	.87668	71	34			35.0		34.5	
35	8.80508	69	8.83373	74	8.84582	66	8.87739	71	35			46.6		46.0	
36	.80577	69	.83447	74	.84648	66	.87810	71	36			58.3		57.5	
37	.80647	69	.83521	74	.84714	66	.87881	71	37						
38	.80716	69	.83595	74	.84780	66	.87953	71	38			67		66	
39	.80786	69	.83670	74	.84846	66	.88024	71	39			6.7		6.6	
40	8.80855	69	8.83744	74	8.84912	66	8.88095	71	40			7.8		7.7	
41	.80924	69	.83818	74	.84978	66	.88166	71	41			8.9		8.8	
42	.80993	69	.83892	74	.85044	66	.88237	71	42			10.0		9.9	
43	.81063	69	.83966	74	.85110	66	.88308	71	43			11.1		11.0	
44	.81132	69	.84039	73	.85176	66	.88378	70	44			22.3		22.0	
45	8.81201	69	8.84113	74	8.85242	65	8.88449	71	45			33.5		33.0	
46	.81270	69	.84187	73	.85308	66	.88520	71	46			44.6		44.0	
47	.81339	69	.84261	74	.85373	65	.88591	70	47			55.8		55.0	
48	.81407	69	.84334	73	.85439	66	.88661	71	48						
49	.81476	68	.84408	73	.85505	65	.88732	71	49						
50	8.81545	68	8.84481	73	8.85570	65	8.88803	70	50						
51	.81614	68	.84555	73	.85626	65	.88873	70	51			0		0.0	
52	.81682	68	.84628	73	.85701	65	.88944	70	52			6		0.0	
53	.81751	68	.84702	73	.85766	65	.89014	70	53			7		0.0	
54	.81819	68	.84775	73	.85832	65	.89085	70	54			8		0.1	
55	8.81888	68	8.84848	73	8.85897	65	8.89155	70	55			10		0.1	
56	.81956	68	.84922	73	.85962	65	.89225	70	56			20		0.1	
57	.82025	68	.84995	73	.86027	65	.89295	70	57			30		0.2	
58	.82093	68	.85068	73	.86092	65	.89366	70	58			40		0.3	
59	.82161	68	.85141	73	.86158	65	.89436	70	59			50		0.4	
60	8.82229		8.85214		8.86223		8.89506		60						
Log. Vers.		D	Log. Exsec.	D	Log. Vers.		D	Log. Exsec.	D					P. P.	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

22°

23°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	8.86223	64	8.89506	76	8.90034	62	8.93631	69	0	
1	.86287	65	.89576	76	.90096	62	.93699	69	1	
2	.86352	65	.89646	76	.90158	62	.93766	69	2	
3	.86417	65	.89716	69	.90220	62	.93833	69	3	
4	.86482	64	.89786	70	.90282	62	.93901	67	4	
5	8.86547	65	8.89856	70	8.90344	62	8.93968	67	5	6
6	.86612	64	.89926	69	.90406	61	.94035	67	6	7
7	.86676	64	.89995	70	.90467	62	.94102	67	7	8
8	.86741	64	.90065	69	.90529	61	.94170	67	8	9
9	.86805	64	.90135	70	.90591	61	.94237	67	9	10
10	8.86870	64	8.90205	69	8.90652	62	8.94304	67	10	20
11	.86934	64	.90274	69	.90714	61	.94371	67	11	30
12	.86999	64	.90344	69	.90776	61	.94438	67	12	40
13	.87063	64	.90413	69	.90837	61	.94505	67	13	50
14	.87127	64	.90483	69	.90899	61	.94572	67	14	
15	8.87192	64	8.90552	69	8.90960	61	8.94638	67	15	
16	.87256	64	.90622	69	.91021	61	.94705	67	16	
17	.87320	64	.90691	69	.91083	61	.94772	67	17	
18	.87384	64	.90760	69	.91144	61	.94839	67	18	
19	.87448	64	.90830	69	.91205	61	.94905	67	19	
20	8.87512	64	8.90899	69	8.91267	61	8.94972	67	20	
21	.87576	64	.90968	69	.91328	61	.95039	67	21	
22	.87640	64	.91037	69	.91389	61	.95105	67	22	
23	.87704	63	.91106	69	.91450	61	.95172	67	23	
24	.87768	64	.91175	69	.91511	61	.95238	67	24	
25	8.87832	63	8.91244	69	8.91572	61	8.95305	67	25	
26	.87895	64	.91313	68	.91633	61	.95371	67	26	
27	.87959	63	.91382	69	.91694	61	.95437	67	27	
28	.88023	63	.91451	69	.91755	60	.95504	67	28	
29	.88086	63	.91520	68	.91815	61	.95570	67	29	
30	8.88150	63	8.91588	69	8.91876	60	8.95636	67	30	
31	.88213	63	.91657	68	.91937	60	.95703	67	31	
32	.88277	63	.91726	68	.91997	61	.95769	67	32	
33	.88340	63	.91794	68	.92058	60	.95835	67	33	
34	.88404	63	.91863	69	.92119	60	.95901	67	34	
35	8.88467	63	8.91932	68	8.92179	60	8.95967	67	35	
36	.88530	63	.92000	68	.92240	60	.96033	67	36	
37	.88593	63	.92068	68	.92300	60	.96099	67	37	
38	.88656	63	.92137	68	.92361	60	.96165	67	38	
39	.88720	63	.92205	68	.92421	60	.96231	67	39	
40	8.88783	63	8.92274	68	8.92487	60	8.96297	67	40	
41	.88846	63	.92342	68	.92542	60	.96362	67	41	
42	.88909	62	.92410	68	.92602	60	.96428	67	42	
43	.88971	63	.92478	68	.92662	60	.96494	67	43	
44	.89034	63	.92546	68	.92722	60	.96560	67	44	
45	8.89097	62	8.92615	68	8.92782	60	8.96625	67	45	
46	.89160	63	.92683	68	.92842	60	.96691	67	46	
47	.89223	62	.92751	68	.92902	60	.96757	67	47	
48	.89285	62	.92819	68	.92962	60	.96822	67	48	
49	.89348	63	.92887	68	.93022	60	.96888	67	49	
50	8.89411	62	8.92955	67	8.93082	59	.96953	67	50	
51	.89473	62	.93022	68	.93142	60	.97018	67	51	
52	.89536	62	.93090	67	.93202	59	.97083	67	52	
53	.89598	62	.93158	68	.93261	60	.97148	67	53	
54	.89660	62	.93226	67	.93321	59	.97213	67	54	
55	8.89723	62	8.93293	68	8.93381	59	8.97280	67	55	
56	.89785	62	.93361	67	.93440	60	.97345	67	56	
57	.89847	62	.93429	67	.93500	59	.97410	67	57	
58	.89910	62	.93496	67	.93560	59	.97475	67	58	
59	.89972	62	.93564	67	.93619	59	.97540	67	59	
60	8.90034	62	8.93631	67	8.93670	59	8.97606	67	60	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

24°

25°

												P. P.				
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D							
0	8.93679	59	8.97606	65	0	8.97170	57	9.01443	62	0						
1	.93738	59	.97671	65	1	.97227	56	.01505	63	1						
2	.93797	59	.97736	65	2	.97284	57	.01568	62	2						
3	.93857	59	.97801	64	3	.97341	57	.01631	63	3						
4	.93916	59	.97865	65	4	.97398	57	.01694	62	4						
5	8.93975	59	8.97930	65	5	8.97455	56	9.01756	63	5	6	65	64	63		
6	.94034	59	.97995	64	6	.97511	56	.01819	62	6	7	6.5	6.4	6.3		
7	.94094	59	.98060	65	7	.97568	56	.01882	62	7	8	7.6	7.4	7.3		
8	.94153	59	.98125	65	8	.97625	56	.01944	62	8	9	8.6	8.5	8.4		
9	.94212	59	.98190	64	9	.97681	56	.02007	63	9	10	9.7	9.6	9.4		
10	8.94271	59	8.98254	64	10	8.97738	56	9.02070	62	10	20	10.8	10.6	10.5		
11	.94330	59	.98319	64	11	.97795	56	.02132	62	11	30	21.6	21.3	21.2		
12	.94389	59	.98383	65	12	.97851	56	.02195	62	12	40	32.5	32.0	31.9		
13	.94448	59	.98448	64	13	.97908	56	.02257	62	13	50	43.3	42.6	42.5		
14	.94506	58	.98513	64	14	.97964	56	.02319	62	14		54.1	53.3	52.1		
15	8.94565	59	8.98577	64	15	8.98020	56	9.02382	62	15						
16	.94624	59	.98642	64	16	.98077	56	.02444	62	16	6	62	61	60		
17	.94683	58	.98706	64	17	.98133	56	.02506	62	17	7	6.2	6.1	6.0		
18	.94742	59	.98770	64	18	.98190	56	.02569	62	18	8	7.2	7.1	7.0		
19	.94800	58	.98835	64	19	.98246	56	.02631	62	19	9	8.2	8.1	8.0		
20	8.94859	58	8.98899	64	20	8.98302	56	9.02693	62	20	10	9.3	9.1	9.0		
21	.94917	58	.98963	64	21	.98358	56	.02755	62	21	20	10.3	10.1	10.0		
22	.94976	58	.99028	64	22	.98414	56	.02817	62	22	30	20.6	20.3	20.0		
23	.95034	58	.99092	64	23	.98470	56	.02880	62	23	40	31.0	30.5	30.0		
24	.95093	58	.99156	64	24	.98527	56	.02942	62	24	50	41.3	40.6	40.0		
25	8.95151	58	8.99220	64	25	8.98583	56	9.03004	62	25						
26	.95210	58	.99284	64	26	.98639	56	.03066	62	26						
27	.95268	58	.99348	64	27	.98695	55	.03128	62	27	6	59	58	57		
28	.95326	58	.99412	64	28	.98750	55	.03190	62	28	7	5.9	5.8	5.7		
29	.95384	58	.99476	64	29	.98806	56	.03252	62	29	8	6.9	6.7	6.6		
30	8.95443	58	8.99540	64	30	8.98802	56	9.03313	61	30	9	7.8	7.7	7.6		
31	.95501	58	.99604	64	31	.98918	56	.03375	62	31	10	8.8	8.7	8.6		
32	.95559	58	.99668	64	32	.98974	55	.03437	62	32	20	9.8	9.6	9.5		
33	.95617	58	.99732	63	33	.99030	56	.03499	62	33	30	19.6	19.3	19.0		
34	.95675	58	.99796	63	34	.99085	55	.03561	62	34	40	29.5	29.0	28.5		
35	8.95733	58	8.99860	64	35	8.99141	55	9.03622	61	35	50	39.3	38.6	38.0		
36	.95791	58	.99923	63	36	.99197	56	.03684	61	36		49.1	48.3	47.5		
37	.95849	57	8.99987	64	37	.99252	55	.03746	61	37						
38	.95907	58	9.00051	63	38	.99308	55	.03807	61	38						
39	.95965	58	.00114	63	39	.99363	55	.03869	61	39	6	56	55	54		
40	8.96023	58	9.00178	64	40	8.99419	55	9.03930	61	40	7	5.6	5.5	5.4		
41	.96080	57	.00242	63	41	.99474	55	.03992	61	41	8	6.5	6.4	6.3		
42	.96138	57	.00305	63	42	.99529	55	.04053	61	42	9	7.4	7.3	7.2		
43	.96196	58	.00369	63	43	.99585	55	.04115	61	43	10	8.4	8.2	8.1		
44	.96253	57	.00432	63	44	.99640	55	.04176	61	44	20	9.3	9.1	9.0		
45	8.96311	57	9.00495	63	45	8.99695	55	9.04238	61	45	30	18.6	18.3	18.0		
46	.96368	57	.00559	63	46	.99751	55	.04299	61	46	40	28.0	27.5	27.0		
47	.96426	57	.00622	63	47	.99806	55	.04360	61	47	50	37.3	36.6	36.0		
48	.96483	57	.00686	63	48	.99861	55	.04421	61	48		46.6	45.8	45.0		
49	.96541	57	.00749	63	49	.99916	55	.04483	61	49						
50	8.96598	57	9.00812	63	50	8.99971	55	9.04544	61	50						
51	.96656	57	.00875	63	51	9.00026	55	.04605	61	51	6	8	0.6	0.6		
52	.96713	57	.00938	63	52	.00081	55	.04666	61	52	7	0.6	0.6	0.6		
53	.96770	57	.01002	63	53	.00136	55	.04727	61	53	8	0.6	0.6	0.6		
54	.96827	57	.01065	63	54	.00191	55	.04788	61	54	9	0.6	0.6	0.6		
55	8.96885	57	9.01128	63	55	9.00246	55	9.04850	61	55	10	0.6	0.6	0.6		
56	.96942	57	.01191	63	56	.00301	55	.04911	61	56	20	0.6	0.6	0.6		
57	.96999	57	.01254	63	57	.00356	55	.04972	61	57	30	0.6	0.6	0.6		
58	.97056	57	.01317	63	58	.00411	54	.05033	60	58	40	0.6	0.6	0.6		
59	.97113	57	.01380	63	59	.00466	54	.05093	61	59	50	0.6	0.6	0.6		
60	8.97170	57	9.01443	63	60	9.00520	54	9.05154	61	60						
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D							P. P.

26° **27°**

Log. Vern.				Log. Exec.				P. P.			
0	9.00520	55	9.05154	61	9.03740	52	9.08752	59	0		
1	.00573	54	.05213	61	.03792	52	.08811	59	1	61	60
2	.00630	54	.05276	60	.03845	52	.08870	59	2	6.1	6.0
3	.00684	54	.05337	61	.03898	53	.08929	59	3	7.1	7.0
4	.00739	54	.05398	60	.03950	52	.08988	59	4	8.1	8.0
5	9.00794	55	9.05458	61	9.04002	52	9.09047	59	5	9.1	9.0
6	.00848	54	.05519	60	.04055	52	.09106	58	6	10.1	10.0
7	.00903	54	.05580	60	.04107	52	.09164	59	7	20.3	20.0
8	.00957	54	.05640	60	.04160	52	.09223	59	8	30.5	30.0
9	.01011	54	.05701	61	.04212	52	.09282	58	9	40.6	40.0
10	9.01066	54	9.05762	60	9.04264	52	9.09341	59	10	50.8	50.0
11	.01120	54	.05822	60	.04317	52	.09400	58	11		
12	.01174	54	.05883	60	.04369	52	.09458	59	12		
13	.01229	54	.05943	60	.04421	52	.09517	58	13		
14	.01283	54	.06004	60	.04473	52	.09576	58	14		
15	9.01337	54	9.06064	60	9.04525	52	9.09634	58	15		
16	.01391	54	.06124	60	.04577	52	.09693	59	16	58	57
17	.01445	54	.06185	60	.04630	52	.09752	58	17	5.8	5.7
18	.01499	54	.06245	60	.04682	52	.09810	58	18	6.7	6.6
19	.01554	54	.06305	60	.04734	52	.09869	58	19	7.7	7.6
20	9.01608	54	9.06366	60	9.04786	51	9.09927	58	20	8.7	8.5
21	.01662	53	.06426	60	.04837	52	.09986	58	21	9.6	9.5
22	.01715	54	.06486	60	.04889	52	.10044	58	22	10.3	10.0
23	.01769	54	.06546	60	.04941	52	.10102	58	23	20.0	20.0
24	.01823	54	.06606	60	.04993	52	.10161	58	24	30.6	30.0
25	9.01877	53	9.06667	60	9.05045	51	9.10219	58	25	40.3	40.0
26	.01931	54	.06727	60	.05097	51	.10278	58	26	48.3	47.5
27	.01985	53	.06787	60	.05148	52	.10336	58	27		
28	.02038	54	.06847	60	.05200	52	.10394	58	28	55	54
29	.02092	53	.06907	60	.05252	51	.10452	58	29	5.5	5.4
30	9.02146	53	9.06967	60	9.05303	52	9.10511	58	30	6.4	6.3
31	.02199	54	.07027	60	.05355	51	.10569	58	31	7.3	7.2
32	.02253	53	.07087	59	.05407	51	.10627	58	32	8.2	8.1
33	.02307	53	.07146	60	.05458	51	.10685	58	33	9.2	9.0
34	.02360	53	.07206	60	.05510	51	.10743	58	34	10.3	10.0
35	9.02414	53	9.07266	59	9.05561	51	9.10801	58	35	20.5	20.0
36	.02467	53	.07326	60	.05613	51	.10859	58	36	30.6	30.0
37	.02521	53	.07386	59	.05664	51	.10917	58	37	40.8	40.0
38	.02574	53	.07445	60	.05715	51	.10975	58	38	45.8	45.0
39	.02627	53	.07505	59	.05767	51	.11033	58	39		
40	9.02681	53	9.07565	59	9.05818	51	9.11091	58	40	53	52
41	.02734	53	.07624	59	.05869	51	.11149	58	41	5.3	5.2
42	.02787	53	.07684	59	.05921	51	.11207	58	42	6.2	6.0
43	.02840	53	.07743	59	.05972	51	.11265	58	43	7.0	6.9
44	.02894	53	.07803	60	.06023	51	.11323	58	44	7.9	7.8
45	9.02947	53	9.07863	59	9.06074	51	9.11380	58	45	8.8	8.6
46	.03000	53	.07922	59	.06125	51	.11438	58	46	17.6	17.3
47	.03053	53	.07981	59	.06176	51	.11496	58	47	26.5	26.0
48	.03106	53	.08041	59	.06227	51	.11554	58	48	35.3	34.0
49	.03159	53	.08100	59	.06279	51	.11611	58	49	44.1	43.3
50	9.03212	53	9.08160	59	9.06330	51	9.11669	58	50		
51	.03265	53	.08219	59	.06380	51	.11727	58	51	51	8
52	.03318	53	.08278	59	.06431	51	.11784	58	52	5.1	0.0
53	.03371	52	.08338	59	.06482	51	.11842	58	53	5.9	0.0
54	.03423	53	.08397	59	.06533	51	.11899	58	54	6.8	0.0
55	9.03476	53	9.08456	59	9.06584	51	9.11957	58	55	7.6	0.1
56	.03529	52	.08515	59	.06635	51	.12015	58	56	8.5	0.1
57	.03582	52	.08574	59	.06686	51	.12072	58	57	17.0	0.2
58	.03634	53	.08634	59	.06736	51	.12129	58	58	25.8	0.3
59	.03687	52	.08693	59	.06787	51	.12187	58	59	34.0	0.4
60	9.03740		9.08752		9.06838		9.12244		60	42.5	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

28°

29°

												P. P.			
	Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D							
0	9.06838	50	9.12244	57	9.09823	49	9.15641	56	0						
1	.06888	51	.12302	57	.09872	48	.15697	55	1						
2	.06939	50	.12359	57	.09920	49	.15752	56	2						
3	.06990	50	.12416	57	.09969	48	.15808	55	3						
4	.07040	50	.12474	57	.10018	48	.15864	55	4	6	57	57	56		
5	9.07091	50	9.12531	57	9.10067	49	9.15920	56	5	7	5.7	5.7	5.7		
6	.07141	50	.12588	57	.10115	48	.15975	55	6	8	6.7	6.6	6.7		
7	.07192	50	.12645	57	.10164	48	.16031	56	7	9	7.6	7.6	7.6		
8	.07242	50	.12703	57	.10213	49	.16087	55	8	10	8.6	8.5	8.5		
9	.07293	50	.12760	57	.10261	48	.16142	55	9	20	9.6	9.5	9.4		
10	9.07343	50	9.12817	57	9.10310	48	9.16198	56	10	30	19.1	19.0	18.1		
11	.07393	50	.12874	57	.10358	48	.16254	55	11	40	28.7	28.5	28.1		
12	.07444	50	.12931	57	.10407	48	.16309	55	12	50	38.3	38.0	37.1		
13	.07494	50	.12988	57	.10455	48	.16365	55	13						
14	.07544	50	.13045	57	.10504	48	.16420	55	14	6	56	55	55		
15	9.07594	50	9.13102	57	9.10552	48	9.16476	55	15	7	5.6	5.5	5.5		
16	.07644	50	.13159	57	.10601	48	.16531	55	16	8	6.5	6.5	6.4		
17	.07695	50	.13216	57	.10649	48	.16587	55	17	9	7.4	7.4	7.4		
18	.07745	50	.13273	56	.10697	48	.16642	55	18	10	8.4	8.3	8.3		
19	.07795	50	.13330	57	.10746	48	.16698	55	19	20	9.3	9.2	9.1		
20	9.07845	50	9.13387	57	9.10794	48	9.16753	55	20	30	18.6	18.5	18.1		
21	.07895	50	.13444	57	.10842	48	.16808	55	21	40	28.0	27.7	27.5		
22	.07945	50	.13500	56	.10890	48	.16864	55	22	50	37.3	37.0	36.0		
23	.07995	50	.13557	57	.10939	48	.16919	55	23						
24	.08045	50	.13614	56	.10987	48	.16974	55	24	6	54	54			
25	9.08095	50	9.13671	57	9.11035	48	9.17029	55	25	7	5.4	5.4			
26	.08145	50	.13727	56	.11083	48	.17085	55	26	8	6.3	6.3			
27	.08195	50	.13784	57	.11131	48	.17140	55	27	9	7.2	7.2			
28	.08244	49	.13841	56	.11179	48	.17195	55	28	10	8.2	8.1			
29	.08294	50	.13897	56	.11227	48	.17250	55	29	20	9.1	9.0			
30	9.08344	49	9.13954	57	9.11275	48	9.17305	55	30	30	18.1	18.0			
31	.08394	50	.14011	56	.11323	48	.17361	55	31	40	27.2	27.0			
32	.08443	49	.14067	56	.11371	48	.17416	55	32	50	36.3	36.0			
33	.08493	49	.14124	56	.11419	47	.17471	55	33						
34	.08543	50	.14180	56	.11467	48	.17526	55	34	6	51	50	50		
35	9.08592	49	9.14237	56	9.11515	48	9.17581	55	35	7	5.1	5.0	5.0		
36	.08642	49	.14293	56	.11562	47	.17636	55	36	8	5.9	5.9	5.7		
37	.08691	49	.14350	56	.11610	48	.17691	55	37	9	6.8	6.7	6.7		
38	.08741	49	.14406	56	.11658	48	.17746	55	38	10	7.6	7.6	7.6		
39	.08790	49	.14462	56	.11706	47	.17801	55	39	20	8.5	8.4	8.4		
40	9.08840	49	9.14519	56	9.11754	48	9.17856	55	40	30	17.0	16.8	16.7		
41	.08889	49	.14575	56	.11801	47	.17910	54	41	40	25.5	25.2	25.0		
42	.08939	49	.14631	56	.11849	47	.17965	55	42	50	34.0	33.6	33.3		
43	.08988	49	.14688	56	.11897	48	.18020	55	43						
44	.09037	49	.14744	56	.11944	47	.18075	54	44	6	49	49	48		
45	9.09087	49	9.14800	56	9.11992	47	9.18130	55	45	7	4.9	4.9	4.9		
46	.09136	49	.14856	56	.12039	47	.18185	55	46	8	5.8	5.7	5.7		
47	.09185	49	.14913	56	.12087	47	.18239	54	47	9	6.6	6.5	6.4		
48	.09234	49	.14969	56	.12134	47	.18294	55	48	10	7.4	7.3	7.3		
49	.09284	49	.15025	56	.12182	47	.18349	54	49	20	8.3	8.1	8.1		
50	9.09333	49	9.15081	56	9.12229	47	9.18403	54	50	30	16.5	16.3	16.1		
51	.09382	49	.15137	56	.12277	47	.18458	55	51	40	24.7	24.5	24.1		
52	.09431	49	.15193	56	.12324	47	.18513	54	52	50	33.0	32.6	32.1		
53	.09480	49	.15249	56	.12371	47	.18567	54	53						
54	.09529	49	.15305	56	.12419	47	.18622	54	54	6	48	47	47		
55	9.09578	49	9.15361	56	9.12466	47	9.18676	54	55	7	4.8	4.7	4.7		
56	.09627	49	.15417	56	.12513	47	.18731	54	56	8	5.6	5.5	5.5		
57	.09676	49	.15473	56	.12560	47	.18786	55	57	9	6.4	6.3	6.3		
58	.09725	48	.15529	56	.12608	47	.18840	54	58	10	7.2	7.1	7.1		
59	.09774	49	.15585	55	.12655	47	.18894	54	59	20	8.0	7.9	7.9		
60	9.09823	49	9.15641	56	9.12702	47	9.18949	54	60	30	16.0	15.8	15.7		
	Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D							

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

30°

31°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.12702	47	9.18949	54	9.15483	45	9.22176	53	0	
1	.12749	47	.19003	54	.15528	45	.22226	53	1	
2	.12796	47	.19058	54	.15574	45	.22282	53	2	
3	.12843	47	.19112	54	.15619	45	.22335	53	3	
4	.12890	47	.19167	54	.15665	45	.22388	53	4	
5	9.12937	47	9.19221	54	9.15710	45	9.22441	53	5	
6	.12984	47		54	.15755	45	.22494	53	6	
7	.13031	47		54	.15801	45	.22547	53	7	
8	.13078	47		54	.15846	45	.22600	53	8	
9	.13125	47		54	.15891	45	.22653	53	9	
10	9.13172	47		54	9.15937	45	9.22706	53	10	
11	.13219	46		54	.15982	45	.22759	53	11	
12	.13266	47		54	.16027	45	.22812	53	12	
13	.13313	47	.19655	54	.16073	45	.22865	53	13	
14	.13359	46	.19709	54	.16118	45	.22918	52	14	
15	9.13406	47	9.19763	54	9.16163	45	.22971	53	15	
16	.13453	46	.19817	54	.16208	45	.23024	53	16	
17	.13500	47	.19871	54	.16253	45	.23076	52	17	
18	.13546	46	.19925	54	.16298	45	.23129	53	18	
19	.13593	46	.19970	54	.16343	45	.23182	52	19	
20	9.13639	46	9.20033	54	9.16388	45	9.23235	53	20	
21	.13686	47	.20087	54	.16434	45	.23287	52	21	
22	.13733	46	.20141	54	.16479	45	.23340	53	22	
23	.13779	46	.20195	54	.16523	44	.23393	52	23	
24	.13826	46	.20249	54	.16568	45	.23446	53	24	
25	9.13872	46	9.20303	53	9.16613	45	9.23498	52	25	
26	.13919	46	.20357	54	.16658	45	.23551	52	26	
27	.13965	46	.20411	54	.16703	45	.23603	52	27	
28	.14011	46	.20465	54	.16748	45	.23656	52	28	
29	.14058	46	.20518	53	.16793	44	.23709	53	29	
30	9.14104	46	9.20572	54	9.16838	45	9.23761	52	30	
31	.14151	46	.20626	53	.16882	44	.23814	52	31	
32	.14197	46	.20680	54	.16927	45	.23866	52	32	
33	.14243	46	.20733	53	.16972	44	.23919	52	33	
34	.14289	46	.20787	54	.17017	45	.23971	52	34	
35	9.14336	46	9.20841	53	9.17061	44	9.24024	53	35	
36	.14382	46	.20894	53	.17106	44	.24076	52	36	
37	.14428	46	.20948	54	.17151	45	.24128	52	37	
38	.14474	46	.21002	53	.17195	44	.24181	52	38	
39	.14520	46	.21056	52	.17240	44	.24233	52	39	
40	9.14566	46	9.21109	53	9.17284	44	9.24285	52	40	
41	.14612	46	.21162	53	.17329	44	.24338	52	41	
42	.14658	46	.21216	53	.17373	44	.24390	52	42	
43	.14704	46	.21269	53	.17418	44	.24442	52	43	
44	.14750	46	.21323	53	.17462	44	.24495	52	44	
45	9.14796	46	9.21376	53	9.17507	44	9.24547	52	45	
46	.14842	46	.21430	53	.17551	44	.24599	52	46	
47	.14888	46	.21483	53	.17596	44	.24651	52	47	
48	.14934	45	.21537	53	.17640	44	.24704	52	48	
49	.14980	45	.21590	53	.17684	44	.24756	52	49	
50	9.15026	45	9.21643	53	9.17729	44	9.24808	52	50	
51	.15071	46	.21697	53	.17773	44	.24860	52	51	
52	.15117	46	.21750	53	.17817	44	.24912	52	52	
53	.15163	45	.21803	53	.17861	44	.24964	52	53	
54	.15209	45	.21857	53	.17906	44	.25016	52	54	
55	9.15254	45	9.21910	53	9.17950	44	9.25068	52	55	
56	.15300	45	.21963	53	.17994	44	.25120	52	56	
57	.15346	45	.22016	53	.18038	44	.25172	52	57	
58	.15391	45	.22070	53	.18082	44	.25224	52	58	
59	.15437	46	.22123	53	.18126	44	.25276	52	59	
60	0.15483		0.22176		0.18170		0.25328		60	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

32°

33°

32°					33°					P. P.				
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'				
0	9.18170		9.25328		0	9.20771		9.28412		0				
1	.18214	44	.25380	52	1	.20814	42	.28463	51	1				
2	.18258	44	.25432	52	2	.20856	42	.28514	51	2				
3	.18302	44	.25484	52	3	.20899	42	.28564	50	3				
4	.18346	44	.25536	51	4	.20942	43	.28615	51	4				
5	9.18390	44	9.25588	52	5	9.20984	42	9.28666	51	5	6	52	51	51
6	.18434	44	.25640	52	6	.21027	42	.28717	50	6	7	5.2	5.1	5.1
7	.18478	44	.25692	52	7	.21069	42	.28768	51	7	8	6.6	6.0	5.0
8	.18522	44	.25743	51	8	.21112	42	.28818	50	8	9	6.9	6.8	6.5
9	.18566	43	.25795	52	9	.21154	42	.28869	50	9	10	7.8	7.7	7.6
10	9.18610	44	9.25847	51	10	9.21196	42	9.28920	51	10	20	8.6	8.6	8.5
11	.18654	44	.25899	52	11	.21239	42	.28970	50	11	30	17.3	17.1	17.0
12	.18697	43	.25950	51	12	.21281	42	.29021	50	12	40	26.0	25.7	25.5
13	.18741	44	.26002	52	13	.21324	42	.29072	51	13	50	34.6	34.3	34.0
14	.18785	43	.26054	51	14	.21366	42	.29122	50	14		43.3	42.9	42.5
15	9.18829	44	9.26105	51	15	9.21408	42	9.29173	51	15				
16	.18872	43	.26157	52	16	.21451	42	.29223	50	16	6	58	50	49
17	.18916	43	.26209	51	17	.21493	42	.29274	50	17	7	5.0	5.0	4.9
18	.18959	43	.26260	51	18	.21535	42	.29324	50	18	8	5.9	5.8	5.5
19	.19003	44	.26312	51	19	.21577	42	.29375	51	19	9	6.7	6.6	6.5
20	9.19047	43	9.26364	52	20	9.21620	42	9.29426	50	20	10	7.6	7.5	7.4
21	.19090	43	.26415	51	21	.21662	42	.29476	50	21	20	8.4	8.3	8.2
22	.19134	43	.26467	51	22	.21704	42	.29527	50	22	30	16.8	16.6	16.5
23	.19177	43	.26518	51	23	.21746	42	.29577	50	23	40	25.2	25.0	24.0
24	.19221	43	.26570	51	24	.21788	42	.29627	50	24	50	33.6	33.3	33.0
25	9.19264	43	9.26621	51	25	9.21830	42	9.29678	50	25		42.1	41.6	41.4
26	.19308	43	.26673	51	26	.21872	42	.29728	50	26	6			
27	.19351	43	.26724	51	27	.21914	42	.29779	50	27	7	44	43	43
28	.19395	43	.26776	51	28	.21956	42	.29829	50	28	8	4.4	4.3	4.3
29	.19438	43	.26827	51	29	.21998	42	.29879	50	29	9	5.1	5.1	5.0
30	9.19481	43	9.26878	51	30	9.22040	42	9.29930	50	30	10	5.8	5.8	5.7
31	.19525	43	.26930	51	31	.22082	42	.29980	50	31	20	6.6	6.5	6.4
32	.19568	43	.26981	51	32	.22124	42	.30030	50	32	30	7.3	7.2	7.1
33	.19611	43	.27032	51	33	.22166	42	.30081	50	33	40	14.6	14.5	14.4
34	.19654	43	.27084	51	34	.22208	42	.30131	50	34	50	22.0	21.7	21.5
35	9.19698	43	9.27135	51	35	9.22250	42	9.30181	50	35		29.3	29.0	28.0
36	.19741	43	.27186	51	36	.22292	41	.30231	50	36	6	36.6	36.2	35.0
37	.19784	43	.27238	51	37	.22334	42	.30282	50	37	7			
38	.19827	43	.27289	51	38	.22376	42	.30332	50	38	8	42	42	41
39	.19870	43	.27340	51	39	.22417	41	.30382	50	39	9	4.2	4.2	4.2
40	9.19914	43	9.27391	51	40	9.22459	42	9.30432	50	40	10	4.9	4.9	4.9
41	.19957	43	.27443	51	41	.22501	41	.30482	50	41	20	5.6	5.6	5.5
42	.20000	43	.27494	51	42	.22543	42	.30533	50	42	30	6.4	6.3	6.2
43	.20043	43	.27545	51	43	.22584	41	.30583	50	43	40	7.1	7.0	6.9
44	.20086	43	.27596	51	44	.22626	41	.30633	50	44	50	14.1	14.0	13.9
45	9.20129	43	9.27647	51	45	9.22668	42	9.30683	50	45		21.2	21.0	20.0
46	.20172	43	.27698	51	46	.22709	41	.30733	50	46	6	28.3	28.0	27.0
47	.20215	43	.27749	51	47	.22751	41	.30783	50	47	7	35.4	35.0	34.0
48	.20258	43	.27800	51	48	.22792	41	.30833	50	48	8			
49	.20301	43	.27852	51	49	.22834	41	.30883	50	49	9			
50	9.20343	42	9.27903	51	50	9.22876	41	9.30933	50	50	10			
51	.20386	43	.27954	51	51	.22917	41	.30983	50	51	20	4.1	4.1	4.1
52	.20429	43	.28005	51	52	.22959	41	.31033	50	52	30	4.8	4.8	4.8
53	.20472	43	.28056	51	53	.23000	41	.31083	50	53	40	5.4	5.4	5.4
54	.20515	42	.28107	51	54	.23042	41	.31133	50	54	50	6.1	6.1	6.1
55	9.20558	43	9.28157	50	55	9.23083	41	9.31183	49	55		6.8		
56	.20600	42	.28208	51	56	.23124	41	.31233	50	56	6	13.6	13.6	13.5
57	.20643	43	.28259	51	57	.23166	41	.31283	50	57	7	20.5	20.5	20.4
58	.20686	43	.28310	51	58	.23207	41	.31333	50	58	8	27.3	27.3	27.2
59	.20728	42	.28361	51	59	.23248	41	.31383	50	59	9	34.1	34.1	34.0
60	9.20771	43	9.28412	50	60	9.23290	41	9.31432	49	60	10			
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'	P. P.			

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

34°

35°

34°					35°					P. P.			
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'			
0	9.23290	41	9.31432	50	0	9.25731	40	9.34395	49	0			
1	.23331	41	.31482	50	1	.25771	40	.34444	48	1			
2	.23372	41	.31532	50	2	.25811	40	.34492	49	2			
3	.23414	41	.31582	50	3	.25851	40	.34541	49	3			
4	.23455	41	.31632	50	4	.25891	40	.34590	49	4			
5	9.23496	41	9.31681	49	5	9.25931	40	9.34639	49	5			
6	.23537	41	.31731	50	6	.25971	40	.34688	48	6			
7	.23579	41	.31781	49	7	.26011	40	.34737	49	7			
8	.23620	41	.31831	50	8	.26051	39	.34785	48	8			
9	.23661	41	.31880	49	9	.26091	40	.34834	49	9			
10	9.23702	41	9.31930	50	10	9.26131	40	9.34883	49	10			
11	.23743	41	.31980	49	11	.26171	40	.34932	48	11			
12	.23784	41	.32029	49	12	.26210	39	.34980	48	12			
13	.23825	41	.32079	49	13	.26250	40	.35029	49	13			
14	.23866	41	.32129	50	14	.26290	40	.35078	48	14			
15	9.23907	41	9.32178	49	15	9.26330	39	9.35127	49	15			
16	.23948	41	.32228	49	16	.26370	40	.35175	48	16			
17	.23989	41	.32277	49	17	.26409	39	.35224	49	17			
18	.24030	41	.32327	49	18	.26449	40	.35273	48	18			
19	.24071	41	.32377	50	19	.26489	39	.35321	48	19			
20	9.24112	40	9.32426	49	20	9.26528	39	9.35370	48	20			
21	.24153	41	.32476	49	21	.26568	40	.35419	49	21			
22	.24194	41	.32525	49	22	.26608	39	.35467	48	22			
23	.24235	41	.32575	49	23	.26647	39	.35516	48	23			
24	.24275	40	.32624	49	24	.26687	39	.35564	48	24			
25	9.24316	41	9.32673	49	25	9.26726	39	9.35613	48	25			
26	.24357	40	.32723	49	26	.26766	40	.35661	48	26			
27	.24398	41	.32772	49	27	.26806	39	.35710	48	27			
28	.24438	40	.32822	49	28	.26845	39	.35758	48	28			
29	.24479	41	.32871	49	29	.26885	39	.35807	48	29			
30	9.24520	40	9.32920	49	30	9.26924	39	9.35855	48	30			
31	.24561	41	.32970	49	31	.26964	39	.35904	48	31			
32	.24601	40	.33019	49	32	.27003	39	.35952	48	32			
33	.24642	40	.33069	49	33	.27042	39	.36001	48	33			
34	.24682	40	.33118	49	34	.27082	39	.36049	48	34			
35	9.24723	41	9.33167	49	35	9.27121	39	9.36098	48	35			
36	.24764	40	.33216	49	36	.27161	39	.36146	48	36			
37	.24804	40	.33266	49	37	.27200	39	.36194	48	37			
38	.24845	40	.33315	49	38	.27239	39	.36243	48	38			
39	.24885	40	.33364	49	39	.27278	39	.36291	48	39			
40	9.24926	40	9.33413	49	40	9.27318	39	9.36340	48	40			
41	.24966	40	.33463	49	41	.27357	39	.36388	48	41			
42	.25007	40	.33512	49	42	.27396	39	.36436	48	42			
43	.25047	40	.33561	49	43	.27435	39	.36484	48	43			
44	.25087	40	.33610	49	44	.27475	39	.36533	48	44			
45	9.25128	40	9.33659	49	45	9.27514	39	9.36581	48	45			
46	.25168	40	.33708	49	46	.27553	39	.36629	48	46			
47	.25209	40	.33758	49	47	.27592	39	.36678	48	47			
48	.25249	40	.33807	49	48	.27631	39	.36726	48	48			
49	.25289	40	.33856	49	49	.27670	39	.36774	48	49			
50	9.25329	40	9.33905	49	50	9.27709	39	9.36822	48	50			
51	.25370	40	.33954	49	51	.27749	39	.36870	48	51			
52	.25410	40	.34003	49	52	.27788	39	.36919	48	52			
53	.25450	40	.34052	49	53	.27827	39	.36967	48	53			
54	.25490	40	.34101	49	54	.27866	39	.37015	48	54			
55	9.25531	40	9.34150	49	55	9.27905	39	9.37063	48	55			
56	.25571	40	.34199	49	56	.27944	39	.37111	48	56			
57	.25611	40	.34248	49	57	.27982	38	.37159	48	57			
58	.25651	40	.34297	49	58	.28021	39	.37207	48	58			
59	.25691	40	.34346	49	59	.28060	39	.37255	48	59			
60	9.25731	40	9.34395	49	60	9.28099	39	9.37303	48	60			

P. P.			
50	49	49	
6	5.0	4.9	4.9
7	5.8	5.8	5.7
8	6.6	6.6	6.5
9	7.5	7.4	7.3
10	8.3	8.2	8.1
20	16.6	16.5	16.3
30	25.0	24.7	24.5
40	33.3	33.0	32.6
50	41.6	41.2	40.8
48	48	48	
6	4.8	4.8	
7	5.6	5.6	
8	6.4	6.4	
9	7.3	7.2	
10	8.1	8.0	
20	16.1	16.0	
30	24.2	24.0	
40	32.3	32.0	
50	40.4	40.0	
41	41	41	
6	4.1	4.1	
7	4.8	4.8	
8	5.5	5.4	
9	6.2	6.1	
10	6.9	6.8	
20	13.8	13.6	
30	20.7	20.5	
40	27.6	27.3	
50	34.6	34.1	
40	40	40	
6	4.0	4.0	
7	4.7	4.6	
8	5.4	5.3	
9	6.1	6.0	
10	6.7	6.6	
20	13.5	13.3	
30	20.2	20.0	
40	27.0	26.6	
50	33.7	33.3	
39	39	39	
6	3.9	3.9	
7	4.6	4.5	
8	5.2	5.2	
9	5.9	5.8	
10	6.6	6.5	
20	13.1	13.0	
30	19.7	19.5	
40	26.3	26.0	
50	32.9	32.5	
38	38	38	
6	3.8	3.8	
7	4.5	4.5	
8	5.1	5.1	
9	5.8	5.8	
10	6.4	6.4	
20	12.8	12.8	
30	19.2	19.2	
40	25.6	25.6	
50	32.1	32.1	

37°

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39°

Log. Vers.				Log. Exsec.				P. P.			
0	9.32631	36	9.42978	46	9.34802	35	9.45752	45	0		
1	.32668	36	.43024	46	.34837	35	.45797	45	1		
2	.32704	36	.43071	47	.34873	36	.45843	46	2		
3	.32741	37	.43118	46	.34909	35	.45889	46	3	47	46
4	.32778	36	.43164	46	.34944	35	.45935	46	4	6	4.7
5	9.32814	36	9.43211	46	9.34980	35	9.45981	45	5	7	5.5
6	.32851	36	.43257	46	.35016	36	.46027	46	6	8	6.2
7	.32888	37	.43304	46	.35051	35	.46073	46	7	9	7.0
8	.32924	36	.43350	46	.35087	35	.46118	45	8	10	7.7
9	.32961	36	.43396	46	.35122	35	.46164	46	9	20	15.6
10	9.32997	36	9.43443	46	9.35158	35	9.46210	46	10	30	23.5
11	.33034	36	.43489	46	.35193	35	.46256	45	11	40	31.3
12	.33070	36	.43536	46	.35229	35	.46302	46	12	50	39.1
13	.33107	36	.43582	46	.35264	35	.46347	45	13		
14	.33143	36	.43629	46	.35300	35	.46393	46	14	46	45
15	9.33180	36	9.43675	46	9.35335	35	9.46439	45	15	6	4.6
16	.33216	36	.43721	46	.35370	35	.46485	46	16	7	5.3
17	.33252	36	.43768	46	.35406	35	.46530	45	17	8	6.0
18	.33289	36	.43814	46	.35441	35	.46576	46	18	9	6.8
19	.33325	36	.43861	46	.35477	35	.46622	45	19	10	7.6
20	9.33361	36	9.43907	46	9.35512	35	9.46668	46	20	20	15.3
21	.33398	36	.43953	46	.35547	35	.46713	45	21	30	23.0
22	.33434	36	.43999	46	.35583	35	.46759	45	22	40	30.6
23	.33470	36	.44046	46	.35618	35	.46805	45	23	50	38.3
24	.33507	36	.44092	46	.35653	35	.46850	45	24		
25	9.33543	36	9.44138	46	9.35689	35	9.46896	45	25	6	4.5
26	.33579	36	.44185	46	.35724	35	.46942	46	26	7	5.2
27	.33615	36	.44231	46	.35759	35	.46987	45	27	8	6.0
28	.33652	36	.44277	46	.35794	35	.47033	45	28	9	6.7
29	.33688	36	.44323	46	.35829	35	.47078	45	29	10	7.5
30	9.33724	36	9.44370	46	9.35865	35	9.47124	46	30	20	15.0
31	.33760	36	.44416	46	.35900	35	.47170	45	31	30	22.5
32	.33796	36	.44462	46	.35935	35	.47215	45	32	40	30.0
33	.33833	36	.44508	46	.35970	35	.47261	45	33	50	37.5
34	.33869	36	.44554	46	.36005	35	.47306	45	34		
35	9.33905	36	9.44601	46	9.36040	35	9.47352	46	35	37	36
36	.33941	36	.44647	46	.36076	35	.47398	45	36	6	3.7
37	.33977	36	.44693	46	.36111	35	.47443	45	37	7	4.3
38	.34013	36	.44739	46	.36146	35	.47489	45	38	8	4.9
39	.34049	36	.44785	46	.36181	35	.47534	45	39	9	5.5
40	9.34085	36	9.44831	46	9.36216	35	9.47580	45	40	10	6.1
41	.34121	36	.44877	46	.36251	35	.47625	45	41	20	12.1
42	.34157	36	.44924	46	.36286	35	.47671	45	42	30	18.2
43	.34193	36	.44970	46	.36321	35	.47716	45	43	40	24.3
44	.34229	36	.45016	46	.36356	35	.47762	45	44	50	30.4
45	9.34265	36	9.45062	46	9.36391	35	9.47807	45	45		
46	.34301	36	.45108	46	.36426	35	.47852	45	46	6	3.6
47	.34337	36	.45154	46	.36461	35	.47898	45	47	7	4.2
48	.34373	36	.45200	46	.36495	34	.47943	45	48	8	4.8
49	.34408	35	.45246	46	.36530	35	.47989	45	49	9	5.3
50	9.34444	36	9.45292	46	9.36565	35	9.48034	45	50	10	5.9
51	.34480	36	.45338	46	.36600	35	.48080	45	51	20	11.8
52	.34516	35	.45384	46	.36635	34	.48125	45	52	30	17.7
53	.34552	36	.45430	46	.36670	35	.48170	45	53	40	23.6
54	.34587	35	.45476	46	.36705	35	.48216	45	54	50	29.6
55	9.34623	36	9.45522	46	9.36739	34	9.48261	45	55		
56	.34659	35	.45568	46	.36774	35	.48306	45	56	6	3.5
57	.34695	36	.45614	46	.36809	34	.48352	45	57	7	4.1
58	.34730	35	.45660	46	.36844	35	.48397	45	58	8	4.6
59	.34766	36	.45706	46	.36878	34	.48442	45	59	9	5.2
60	9.34802	35	9.45752	46	9.36913	35	9.48488	45	60	10	5.7

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

40°

41°

	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.36913	34	9.48488	45	0	9.51190	45			0	
1	.36948	34	.48533	45	1	.51235	44			1	
2	.36982	34	.48578	45	2	.51279	44			2	
3	.37017	35	.48624	45	3	.51324	45			3	
4	.37052	34	.48669	45	4	.51369	44			4	
5	9.37086	34	9.48714	45	5	9.51414	45			5	45
6	.37121	35	.48759	45	6	.51458	44			6	4.5
7	.37156	34	.48805	45	7	.51503	45			7	5.2
8	.37190	34	.48850	45	8	.51548	44			8	6.0
9	.37225	34	.48895	45	9	.51592	44			9	6.7
10	9.37259	34	9.48940	45	10	9.51637	45			10	7.5
11	.37294	34	.48986	45	11	.51682	44			11	8.2
12	.37328	34	.49031	45	12	.51726	45			12	9.0
13	.37363	34	.49076	45	13	.51771	44			13	9.8
14	.37397	34	.49121	45	14	.51816	44			14	10.6
15	9.37432	34	9.49166	45	15	9.51860	45			15	11.4
16	.37466	34	.49211	45	16	.51905	44			16	12.2
17	.37501	34	.49257	45	17	.51950	44			17	13.0
18	.37535	34	.49302	45	18	.51994	44			18	13.8
19	.37570	34	.49347	45	19	.52039	44			19	14.6
20	9.37604	34	9.49392	45	20	9.52084	45			20	15.4
21	.37639	34	.49437	45	21	.52128	44			21	16.2
22	.37673	34	.49482	45	22	.52173	44			22	17.0
23	.37707	34	.49527	45	23	.52217	44			23	17.8
24	.37742	34	.49572	45	24	.52262	44			24	18.6
25	9.37776	34	9.49618	45	25	9.52306	45			25	19.4
26	.37810	34	.49663	45	26	.52351	44			26	20.2
27	.37845	34	.49708	45	27	.52396	44			27	21.0
28	.37879	34	.49753	45	28	.52440	44			28	21.8
29	.37913	34	.49798	45	29	.52485	44			29	22.6
30	9.37947	34	9.49843	45	30	9.52529	45			30	23.4
31	.37982	34	.49888	45	31	.52574	44			31	24.2
32	.38016	34	.49933	45	32	.52618	44			32	25.0
33	.38050	34	.49978	45	33	.52663	44			33	25.8
34	.38084	34	.50023	45	34	.52707	44			34	26.6
35	9.38118	34	9.50068	45	35	9.52752	45			35	27.4
36	.38153	34	.50113	45	36	.52796	44			36	28.2
37	.38187	34	.50158	45	37	.52841	44			37	29.0
38	.38221	34	.50203	45	38	.52885	44			38	29.8
39	.38255	34	.50248	45	39	.52930	44			39	30.6
40	9.38289	34	9.50293	45	40	9.52974	45			40	31.4
41	.38323	34	.50338	45	41	.53018	44			41	32.2
42	.38357	34	.50383	45	42	.53063	44			42	33.0
43	.38391	34	.50427	45	43	.53107	44			43	33.8
44	.38425	34	.50472	45	44	.53152	44			44	34.6
45	9.38459	34	9.50517	45	45	9.53196	45			45	35.4
46	.38493	34	.50562	45	46	.53240	44			46	36.2
47	.38527	34	.50607	45	47	.53285	44			47	37.0
48	.38561	34	.50652	45	48	.53329	44			48	37.8
49	.38595	34		45	49	.53374	44			49	38.6
50	9.38629	34		45	50	9.53418	45			50	39.4
51	.38663	34		45	51	.53463	44			51	40.2
52	.38697	34		44	52	.53507	44			52	41.0
53	.38731	33		45	53	.53551	44			53	41.8
54	.38765	34		45	54	.53595	44			54	42.6
55	9.38799	34		44	55	9.53640	45			55	43.4
56	.38833	33		45	56	.53684	44			56	44.2
57	.38866	34	.51055	44	57	.53728	44			57	45.0
58	.38900	33	.51100	45	58	.53773	44			58	45.8
59	.38934	33	.51145	45	59	.53817	44			59	46.6
60	9.38968	34	9.51190	44	60	9.53861	45			60	47.4
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D		P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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43°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.40969	32	9.53861	44	9.42918	32	9.56505	43	0	
1	.41001	33	.53906	44	.42950	32	.56549	44	1	
2	.41034	33	.53950	44	.42982	32	.56593	44	2	
3	.41067	33	.53994	44	.43014	32	.56637	43	3	
4	.41100	32	.54038	44	.43046	32	.56680	44	4	
5	9.41133	33	9.54083	44	9.43078	32	9.56724	44	5	6 44 44
6	.41166	33	.54127	44	.43110	32	.56768	44	6	7 4.4 4.4
7	.41199	32	.54171	44	.43142	31	.56812	43	7	8 5.2 5.2
8	.41231	33	.54215	44	.43174	32	.56856	44	8	9 5.9 5.8
9	.41264	33	.54259	44	.43206	32	.56899	43	9	10 6.7 6.6
10	9.41297	32	9.54304	44	9.43238	32	9.56943	44	10	20 7.4 7.3
11	.41330	33	.54348	44	.43270	32	.56987	44	11	30 14.8 14.6
12	.41362	32	.54392	44	.43302	32	.57031	43	12	40 22.2 22.0
13	.41395	33	.54436	44	.43334	32	.57075	44	13	50 29.6 29.3
14	.41428	32	.54480	44	.43365	31	.57118	43	14	
15	9.41461	33	9.54525	44	9.43397	32	9.57162	44	15	
16	.41493	32	.54569	44	.43429	32	.57206	43	16	6 43 43
17	.41526	33	.54613	44	.43461	32	.57250	44	17	7 4.3 4.3
18	.41559	32	.54657	44	.43493	31	.57293	43	18	8 5.1 5.0
19	.41591	32	.54701	44	.43525	32	.57337	44	19	9 5.8 5.7
20	9.41624	33	9.54745	44	9.43557	32	9.57381	43	20	10 6.5 6.4
21	.41657	33	.54790	44	.43588	31	.57424	43	21	20 7.2 7.1
22	.41689	32	.54834	44	.43620	32	.57468	44	22	30 14.5 14.3
23	.41722	32	.54878	44	.43652	31	.57512	43	23	40 21.7 21.5
24	.41754	32	.54922	44	.43684	32	.57556	44	24	50 29.0 28.6
25	9.41787	33	9.54966	44	9.43715	31	9.57599	43	25	
26	.41819	32	.55010	44	.43747	32	.57643	43	26	6 33 32
27	.41852	33	.55054	44	.43779	31	.57687	44	27	7 3.3 3.2
28	.41885	32	.55098	44	.43810	32	.57730	43	28	8 3.8 3.8
29	.41917	32	.55142	44	.43842	31	.57774	44	29	9 4.4 4.3
30	9.41950	33	9.55186	44	9.43874	32	9.57818	43	30	10 4.9 4.9
31	.41982	32	.55230	44	.43906	31	.57861	43	31	20 5.5 5.4
32	.42014	32	.55275	44	.43937	31	.57905	44	32	30 11.0 10.8
33	.42047	33	.55319	44	.43969	31	.57949	43	33	40 16.5 16.2
34	.42079	32	.55363	44	.44000	31	.57992	43	34	50 22.0 21.6
35	9.42112	33	9.55407	44	9.44032	32	9.58036	43	35	
36	.42144	32	.55451	44	.44064	31	.58079	43	36	6 32 31
37	.42177	33	.55495	44	.44095	31	.58123	44	37	7 3.2 3.1
38	.42209	32	.55539	44	.44127	31	.58167	43	38	8 3.7 3.7
39	.42241	32	.55583	44	.44158	31	.58210	43	39	9 4.2 4.2
40	9.42274	33	9.55627	44	9.44190	31	9.58254	43	40	10 4.8 4.7
41	.42306	32	.55671	44	.44221	31	.58297	43	41	20 5.3 5.2
42	.42338	32	.55715	44	.44253	31	.58341	44	42	30 10.6 10.5
43	.42371	32	.55759	44	.44284	31	.58385	43	43	40 16.0 15.7
44	.42403	32	.55803	44	.44316	31	.58428	43	44	50 21.3 21.0
45	9.42435	33	9.55847	44	9.44347	31	9.58472	43	45	
46	.42467	32	.55890	43	.44379	31	.58515	43	46	6 32 31
47	.42500	32	.55934	44	.44410	31	.58559	43	47	7 3.2 3.1
48	.42532	32	.55978	44	.44442	31	.58602	43	48	8 3.7 3.7
49	.42564	32	.56022	44	.44473	31	.58646	43	49	9 4.2 4.2
50	9.42596	33	9.56066	44	9.44504	31	9.58689	43	50	10 4.8 4.7
51	.42629	32	.56110	44	.44536	31	.58733	43	51	20 5.3 5.2
52	.42661	32	.56154	44	.44567	31	.58776	44	52	30 10.6 10.5
53	.42693	32	.56198	43	.44599	31	.58820	43	53	40 16.0 15.7
54	.42725	32	.56242	44	.44630	31	.58864	43	54	50 21.3 21.0
55	9.42757	33	9.56286	44	9.44661	31	9.58907	43	55	
56	.42789	32	.56330	44	.44693	31	.58951	43	56	6 31 31
57	.42822	32	.56374	44	.44724	31	.58994	43	57	7 3.1 3.1
58	.42854	32	.56417	43	.44755	31	.59037	43	58	8 3.6 3.6
59	.42886	32	.56461	44	.44787	31	.59081	43	59	9 4.1 4.1
60		32		43		31		43	60	10 4.6 4.6

44°

45°

Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
9.44818	31	9.59124	43	9.46671	30	9.61722	43	0	
.44849	31	.59168	43	.46701	30	.61765	43	1	
.44880	31	.59211	43	.46732	30	.61808	43	2	
.44912	31	.59255	43	.46762	30	.61852	43	3	
.44943	31	.59298	43	.46793	30	.61895	43	4	
9.44974	31	9.59342	43	9.46823	30	9.61938	43	5	
.45005	31	.59385	43	.46853	30	.61981	43	6	
.45036	31	.59429	43	.46884	30	.62024	43	7	
.45068	31	.59472	43	.46914	30	.62067	43	8	
.45099	31	.59515	43	.46945	30	.62110	43	9	
9.45130	31	9.59559	43	9.46975	30	9.62153	43	10	
.45161	31	.59602	43	.47005	30	.62196	43	11	
.45192	31	.59646	43	.47036	30	.62239	43	12	
.45223	31	.59689	43	.47066	30	.62282	43	13	
.45254	31	.59732	43	.47096	30	.62326	43	14	
9.45285	31	9.59776	43	9.47127	30	9.62369	43	15	
.45316	31	.59819	43	.47157	30	.62412	43	16	
.45348	31	.59863	43	.47187	30	.62455	43	17	
.45379	31	.59906	43	.47218	30	.62498	43	18	
.45410	31	.59949	43	.47248	30	.62541	43	19	
9.45441	31	9.59993	43	9.47278	30	9.62584	43	20	
.45472	31	.60036	43	.47308	30	.62627	43	21	
.45503	31	.60079	43	.47339	30	.62670	43	22	
.45534	31	.60123	43	.47369	30	.62713	43	23	
.45565	31	.60166	43	.47399	30	.62756	43	24	
9.45595	30	9.60209	43	9.47429	30	9.62799	43	25	
.45626	31	.60253	43	.47459	30	.62842	43	26	
.45657	31	.60296	43	.47490	30	.62885	43	27	
.45688	31	.60339	43	.47520	30	.62928	43	28	
.45719	31	.60383	43	.47550	30	.62971	43	29	
9.45750	30	9.60426	43	9.47580	30	9.63014	43	30	
.45781	31	.60469	43	.47610	30	.63057	43	31	
.45812	31	.60512	43	.47640	30	.63100	43	32	
.45843	31	.60556	43	.47670	30	.63143	43	33	
.45873	30	.60599	43	.47700	30	.63186	43	34	
9.45904	31	9.60642	43	9.47731	30	9.63229	43	35	
.45935	31	.60685	43	.47761	30	.63272	43	36	
.45966	30	.60729	43	.47791	30	.63315	43	37	
.45997	31	.60772	43	.47821	30	.63358	43	38	
.46027	30	.60815	43	.47851	30	.63401	43	39	
9.46058	31	9.60858	43	9.47881	30	9.63443	42	40	
.46089	30	.60902	43	.47911	30	.63486	43	41	
.46120	31	.60945	43	.47941	30	.63529	43	42	
.46150	30	.60988	43	.47971	30	.63572	43	43	
.46181	31	.61031	43	.48001	30	.63615	43	44	
9.46212	30	9.61075	43	9.48031	30	9.63658	43	45	
.46242	30	.61118	43	.48061	30	.63701	42	46	
.46273	31	.61161	43	.48090	29	.63744	43	47	
.46304	30	.61204	43	.48120	30	.63787	43	48	
.46334	30	.61247	43	.48150	30	.63830	43	49	
9.46365	31	9.61291	43	9.48180	30	9.63873	43	50	
.46396	30	.61334	43	.48210	30	.63915	42	51	
.46426	30	.61377	43	.48240	29	.63958	43	52	
.46457	30	.61420	43	.48270	30	.64001	43	53	
.46487	30	.61463	43	.48300	30	.64044	43	54	
9.46518	31	9.61506	43	9.48329	29	9.64087	42	55	
.46549	30	.61550	43	.48359	30	.64130	43	56	
.46579	30	.61593	43	.48389	30	.64173	43	57	
.46610	30	.61636	43	.48419	29	.64216	43	58	
.46640	30	.61679	43	.48449	30	.64258	42	59	
9.46671	30	9.61722	43	9.48478	29	9.64301	43	60	
Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.

	43	43
6	4.3	4.3
7	5.1	5.0
8	5.8	5.7
9	6.5	6.4
10	7.2	7.1
20	14.5	14.3
30	21.7	21.5
40	29.0	28.6
50	36.2	35.8

	42	
6	4.2	
7	4.9	
8	5.6	
9	6.4	
10	7.1	
20	14.1	
30	21.2	
40	28.3	
50	35.4	

	31	31
6	3.1	3.1
7	3.7	3.6
8	4.4	4.1
9	4.7	4.9
10	5.2	5.1
20	10.5	10.3
30	15.7	15.5
40	21.0	20.7
50	26.2	25.8

	30	30
6	3.0	3.0
7	3.5	3.5
8	4.0	4.0
9	4.6	4.5
10	5.1	5.0
20	10.1	10.0
30	15.2	15.0
40	20.3	20.0
50	25.4	25.0

	29	
6	2.9	
7	3.4	
8	3.9	
9	4.4	
10	4.9	
20	9.8	
30	14.7	
40	19.6	
50	24.6	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

50°

51°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.55292	27	9.74486	42	9.56900	26	9.77012	42	0	
1	.55316	27	.74528	42	.56926	26	.77055	42	1	
2	.55347	27	.74570	42	.56953	26	.77097	42	2	
3	.55374	27	.74612	42	.56979	26	.77139	42	3	
4	.55401	27	.74654	42	.57005	26	.77181	42	4	
5	9.55428	27	9.74696	42	9.57032	26	9.77223	42	5	
6	.55455	27	.74739	42	.57058	26	.77265	42	6	
7	.55482	27	.74781	42	.57085	26	.77307	42	7	
8	.55509	27	.74823	42	.57111	26	.77349	42	8	42
9	.55536	27	.74865	42	.57138	26	.77391	42	9	4.2
10	9.55563	27	9.74907	42	9.57164	26	9.77433	42	10	4.6
11	.55590	27	.74949	42	.57196	26	.77475	42	11	4.9
12	.55617	27	.74991	42	.57217	26	.77517	42	12	5.6
13	.55644	27	.75033	42	.57243	26	.77560	42	13	6.4
14	.55671	27	.75076	42	.57269	26	.77602	42	14	7.1
15	9.55698	27	9.75118	42	9.57296	26	9.77644	42	15	7.0
16	.55725	27	.75160	42	.57322	26	.77686	42	16	14.0
17	.55751	26	.75202	42	.57348	26	.77728	42	17	21.0
18	.55778	27	.75244	42	.57375	26	.77770	42	18	28.0
19	.55805	27	.75286	42	.57401	26	.77812	42	19	28.0
20	9.55832	27	9.75328	42	9.57427	26	9.77854	42	20	35.4
21	.55859	27	.75370	42	.57454	26	.77896	42	21	
22	.55886	26	.75413	42	.57480	26	.77938	42	22	27
23	.55913	27	.75455	42	.57506	26	.77980	42	23	2.7
24	.55940	27	.75497	42	.57532	26	.78022	42	24	3.1
25	9.55966	26	9.75539	42	9.57559	26	9.78064	42	25	3.6
26	.55993	27	.75581	42	.57585	26	.78107	42	26	4.6
27	.56020	27	.75623	42	.57611	26	.78149	42	27	9.0
28	.56047	26	.75665	42	.57637	26	.78191	42	28	13.5
29	.56074	27	.75707	42	.57664	26	.78233	42	29	18.0
30	9.56101	27	9.75750	42	9.57690	26	9.78275	42	30	22.9
31	.56127	26	.75792	42	.57716	26	.78317	42	31	
32	.56154	27	.75834	42	.57742	26	.78359	42	32	26
33	.56181	26	.75876	42	.57768	26	.78401	42	33	2.6
34	.56208	27	.75918	42	.57794	26	.78443	42	34	3.6
35	9.56234	26	9.75960	42	9.57821	26	9.78485	42	35	3.5
36	.56261	27	.76002	42	.57847	26	.78527	42	36	3.4
37	.56288	26	.76044	42	.57873	26	.78569	42	37	3.9
38	.56315	27	.76086	42	.57899	26	.78611	42	38	4.2
39	.56341	26	.76128	42	.57925	26	.78653	42	39	8.6
40	9.56368	26	9.76171	42	9.57951	26	9.78696	42	40	13.0
41	.56395	27	.76213	42	.57977	26	.78738	42	41	17.3
42	.56421	26	.76255	42	.58003	26	.78780	42	42	21.6
43	.56448	26	.76297	42	.58029	26	.78822	42	43	
44	.56475	27	.76339	42	.58055	26	.78864	42	44	
45	9.56501	26	9.76381	42	9.58082	26	9.78906	42	45	
46	.56528	26	.76423	42	.58108	26	.78948	42	46	25
47		26	.76465	42	.58134	26	.78990	42	47	2.5
48		27	.76507	42	.58160	26	.79032	42	48	3.0
49		26	.76549	42	.58186	26	.79074	42	49	3.4
50	9.56634	26	9.76592	42	9.58212	26	9.79116	42	50	3.8
51	.56661	26	.76634	42	.58238	26	.79158	42	51	4.2
52	.56687	26	.76676	42	.58264	26	.79200	42	52	8.5
53	.56714	26	.76718	42	.58290	26	.79242	42	53	12.7
54	.56741	27	.76760	42	.58316	26	.79285	42	54	17.0
55	9.56767	26	9.76802	42	9.58342	26	9.79327	42	55	21.2
56	.56794	26	.76844	42	.58367	26	.79369	42	56	
57	.56820	26	.76886	42	.58393	26	.79411	42	57	
58	.56847	26	.76928	42	.58419	26	.79453	42	58	
59	.56873	26	.76970	42	.58445	26	.79495	42	59	
60	0.56900		0.77012		0.58471		0.79537		60	

BLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

52°

53°

Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D		P. P.
9.58471	26	9.79537	42	9.60008	25	9.82062	42	0	
.58497	25	.79579	42	.60034	25	.82104	42	1	
.58523	26	.79621	42	.60059	25	.82146	42	2	
.58549	26	.79663	42	.60084	25	.82188	42	3	
.58575	26	.79705	42	.60110	25	.82230	42	4	
9.58601	26	9.79747	42	9.60135	25	9.82272	42	5	
.58626	25	.79789	42	.60160	25	.82315	42	6	
.58652	26	.79831	42	.60185	25	.82357	42	7	
.58678	26	.79874	42	.60211	25	.82399	42	8	
.58704	25	.79916	42	.60236	25	.82441	42	9	
9.58730	26	9.79958	42	9.60261	25	9.82483	42	10	
.58755	25	.80000	42	.60286	25	.82525	42	11	
.58781	26	.80042	42	.60312	25	.82567	42	12	
.58807	26	.80084	42	.60337	25	.82609	42	13	
.58833	25	.80126	42	.60362	25	.82651	42	14	
9.58859	26	9.80168	42	9.60387	25	9.82694	42	15	
.58884	25	.80210	42	.60412	25	.82736	42	16	6 42 42
.58910	26	.80252	42	.60438	25	.82778	42	17	7 4.2 4.2
.58936	25	.80294	42	.60463	25	.82820	42	18	8 4.9 4.9
.58962	26	.80336	42	.60488	25	.82862	42	19	9 5.6 5.6
9.58987	25	9.80378	42	9.60513	25	9.82904	42	20	10 6.4 6.3
.59013	25	.80420	42	.60538	25	.82946	42	21	20 7.1 7.0
.59039	26	.80463	42	.60563	25	.82988	42	22	30 14.1 14.0
.59064	25	.80505	42	.60589	25	.83031	42	23	40 21.2 21.0
.59090	26	.80547	42	.60614	25	.83073	42	24	50 28.3 28.0
9.59116	25	9.80589	42	9.60639	25	9.83115	42	25	
.59141	25	.80631	42	.60664	25	.83157	42	26	
.59167	26	.80673	42	.60689	25	.83199	42	27	
.59193	25	.80715	42	.60714	25	.83241	42	28	
.59218	25	.80757	42	.60739	25	.83283	42	29	6 26 25
9.59244	25	9.80799	42	9.60764	25	9.83325	42	30	7 2.6 2.5
.59270	26	.80841	42	.60789	25	.83368	42	31	8 3.0 3.0
.59295	25	.80883	42	.60814	25	.83410	42	32	9 3.4 3.4
.59321	25	.80925	42	.60839	25	.83452	42	33	10 3.9 3.8
.59346	25	.80968	42	.60864	25	.83494	42	34	20 4.2 4.2
9.59372	25	9.81010	42	9.60889	25	9.83536	42	35	
.59397	25	.81052	42	.60914	25	.83578	42	36	
.59423	26	.81094	42	.60939	25	.83620	42	37	
.59449	25	.81136	42	.60964	25	.83663	42	38	
.59474	25	.81178	42	.60989	25	.83705	42	39	
9.59500	25	9.81220	42	9.61014	25	9.83747	42	40	
.59525	25	.81262	42	.61039	25	.83789	42	41	6 25 24
.59551	25	.81304	42	.61064	25	.83831	42	42	7 2.5 2.4
.59576	25	.81346	42	.61089	25	.83873	42	43	8 2.9 2.8
.59602	25	.81388	42	.61114	25	.83916	42	44	9 3.2 3.2
9.59627	25	9.81430	42	9.61139	25	9.83958	42	45	10 3.7 3.7
.59653	25	.81473	42	.61164	25	.84000	42	46	20 4.1 4.1
.59678	25	.81515	42	.61189	25	.84042	42	47	30 8.3 8.1
.59704	25	.81557	42	.61214	24	.84084	42	48	40 12.5 12.2
.59729	25	.81599	42	.61239	25	.84126	42	49	50 16.6 16.3
9.59754	25	9.81641	42	9.61264	25	9.84168	42	50	
.59780	25	.81683	42	.61289	25	.84211	42	51	6 20.8 20.4
.59805	25	.81725	42	.61313	24	.84253	42	52	
.59831	25	.81767	42	.61338	25	.84295	42	53	
.59856	25	.81809	42	.61363	25	.84337	42	54	
9.59881	25	9.81851	42	9.61388	25	9.84379	42	55	
.59907	25	.81894	42	.61413	24	.84422	42	56	
.59932	25	.81936	42	.61438	25	.84464	42	57	
.59958	25	.81978	42	.61462	24	.84506	42	58	
.59983	25	.82020	42	.61487	25	.84548	42	59	
9.60008	25	9.82062	42	9.61512	25	9.84590	42	60	
Log. Vern.	D	Log. Exsec.	D	Log. Vern.	D	Log. Exsec.	D		P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

54°

55°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	P. P.
0	9.61512	24	9.84590	42	9.62984	24	9.87125	42	
1	.61537	25	.84632	42	.63008	24	.87167	42	
2	.61562	24	.84675	42	.63032	24	.87209	42	
3	.61586	25	.84717	42	.63057	24	.87252	42	
4	.61611	24	.84759	42	.63081	24	.87294	42	
5	9.61636	24	9.84801	42	9.63105	24	9.87336	42	
6	.61661	25	.84843	42	.63129	24	.87379	42	
7	.61685	24	.84886	42	.63154	24	.87421	42	
8	.61710	25	.84928	42	.63178	24	.87463	42	
9	.61735	24	.84970	42	.63202	24	.87506	42	
10	9.61760	25	9.85012	42	9.63226	24	9.87548	42	
11	.61784	24	.85054	42	.63250	24	.87590	42	
12	.61809	24	.85097	42	.63274	24	.87633	42	
13	.61834	25	.85139	42	.63299	24	.87675	42	
14	.61858	24	.85181	42	.63323	24	.87717	42	
15	9.61883	25	9.85223	42	9.63347	24	9.87760	42	
16	.61908	24	.85265	42	.63371	24	.87802	42	
17	.61932	24	.85308	42	.63395	24	.87844	42	
18	.61957	24	.85350	42	.63419	24	.87887	42	
19	.61982	25	.85392	42	.63443	24	.87929	42	
20	9.62006	24	9.85434	42	9.63468	24	9.87971	42	
21	.62031	24	.85476	42	.63492	24	.88014	42	
22	.62055	24	.85519	42	.63516	24	.88056	42	
23	.62080	25	.85561	42	.63540	24	.88099	42	
24	.62105	24	.85603	42	.63564	24	.88141	42	
25	9.62129	24	9.85645	42	9.63588	24	9.88183	42	
26	.62154	24	.85688	42	.63612	24	.88226	42	
27	.62178	24	.85730	42	.63636	24	.88268	42	
28	.62203	24	.85772	42	.63660	24	.88310	42	
29	.62227	24	.85814	42	.63684	24	.88353	42	
30		24	9.85857	42	9.63708	24	9.88395	42	
31		24	.85899	42	.63732	24	.88438	42	
32		24	.85941	42	.63756	24	.88480	42	
33		24	.85983	42	.63780	24	.88522	42	
34		24	.86026	42	.63804	24	.88565	42	
35		24	9.86068	42	9.63828	24	9.88607	42	
36		24	.86110	42	.63852	24	.88650	42	
37		24	.86152	42	.63876	24	.88692	42	
38		24	.86195	42	.63900	24	.88734	42	
39		24	.86237	42	.63924	24	.88777	42	
40	9.62497	24	9.86279	42	9.63948	24	9.88819	42	
41	.62521	24	.86321	42	.63972	24	.88862	42	
42	.62546	24	.86364	42	.63996	24	.88904	42	
43	.62570	24	.86406	42	.64019	24	.88947	42	
44	.62594	24	.86448	42	.64043	24	.88989	42	
45	9.62619	24	9.86490	42	9.64067	24	9.89031	42	
46	.62643	24	.86533	42	.64091	24	.89074	42	
47	.62668	24	.86575	42	.64115	24	.89116	42	
48	.62692	24	.86617	42	.64139	24	.89159	42	
49	.62716	24	.86659	42	.64163	24	.89201	42	
50	9.62741	24	9.86702	42	9.64187	24	9.89244	42	
51	.62765	24	.86744	42	.64210	24	.89286	42	
52	.62789	24	.86786	42	.64234	24	.89329	42	
53	.62814	24	.86829	42	.64258	24	.89371	42	
54	.62838	24	.86871	42	.64282	24	.89414	42	
55		24	9.86913	42	9.64306	24	9.89456	42	
56		24	.86956	42	.64330	24	.89499	42	
57		24	.86998	42	.64353	24	.89541	42	
58		24	.87040	42	.64377	24	.89583	42	
59		24	.87082	42	.64401	24	.89626	42	
60	9.62984	24	9.87125	42	9.64425	24	9.89668	42	

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TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

56°

57°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.64425	23	9.89668	42	9.65835	23	9.92224	43	0	
1	.64448	24	.89711	42	.65859	23	.92267	42	1	
2	.64472	23	.89753	42	.65882	23	.92310	43	2	
3	.64496	24	.89796	42	.65905	23	.92353	42	3	
4	.64520	23	.89838	42	.65928	23	.92395	43	4	
5	9.64543	24	9.89881	42	9.65952	23	9.92438	42	5	
6	.64567	23	.89923	42	.65975	23	.92481	43	6	
7	.64591	23	.89966	42	.65998	23	.92524	42	7	
8	.64614	24	.90008	42	.66021	23	.92566	43	8	
9	.64638	23	.90051	42	.66044	23	.92609	42	9	
10	9.64662	23	9.90094	43	9.66068	23	9.92652	43	10	
11	.64685	24	.90136	42	.66091	23	.92695	42	11	
12	.64709	23	.90179	42	.66114	23	.92737	43	12	
13	.64733	23	.90221	42	.66137	23	.92780	42	13	
14	.64756	24	.90264	42	.66160	23	.92823	43	14	
15	9.64780	23	9.90306	42	9.66183	23	.92865	42	15	
16	.64804	23	.90349	42	.66207	23	.92909	43	16	
17	.64827	23	.90391	42	.66230	23	.92951	42	17	
18	.64851	24	.90434	42	.66253	23	.92994	43	18	
19	.64875	23	.90476	42	.66276	23	.93037	42	19	
20	9.64898	23	9.90519	42	9.66299	23	9.93080	43	20	
21	.64922	23	.90561	42	.66322	23	.93123	42	21	
22	.64945	23	.90604	42	.66345	23	.93165	43	22	
23	.64969	23	.90647	42	.66368	23	.93208	42	23	
24	.64992	24	.90689	42	.66391	23	.93251	43	24	
25	9.65016	23	9.90732	42	9.66415	23	9.93294	42	25	
26	.65040	23	.90774	42	.66438	23	.93337	43	26	
27	.65063	23	.90817	42	.66461	23	.93380	42	27	
28	.65087	23	.90860	43	.66484	23	.93422	43	28	
29	.65110	23	.90902	42	.66507	23	.93465	42	29	
30	9.65134	23	9.90945	42	9.66530	23	9.93508	43	30	
31	.65157	23	.90987	42	.66553	23	.93551	42	31	
32	.65181	23	.91030	42	.66576	23	.93594	43	32	
33	.65204	23	.91073	43	.66599	23	.93637	42	33	
34	.65228	23	.91115	42	.66622	23	.93680	43	34	
35	9.65251	23	9.91158	42	9.66645	23	9.93722	42	35	
36	.65275	23	.91200	42	.66668	23	.93765	43	36	
37	.65298	23	.91243	42	.66691	23	.93808	42	37	
38	.65321	23	.91286	43	.66714	23	.93851	43	38	
39	.65345	23	.91328	42	.66737	23	.93894	42	39	
40	9.65368	23	9.91371	42	9.66760	23	9.93937	43	40	
41	.65392	23	.91414	42	.66783	23	.93980	42	41	
42	.65415	23	.91456	42	.66805	23	.94023	43	42	
43	.65439	23	.91499	42	.66828	23	.94066	42	43	
44	.65462	23	.91541	42	.66851	23	.94109	43	44	
45	9.65485	23	9.91584	42	9.66874	23	9.94151	42	45	
46	.65509	23	.91627	42	.66897	23	.94194	43	46	
47	.65532	23	.91669	42	.66920	23	.94237	42	47	
48	.65556	23	.91712	43	.66943	23	.94280	43	48	
49	.65579	23	.91755	42	.66966	23	.94323	42	49	
50	9.65602	23	9.91797	42	9.66989	23	9.94366	43	50	
51	.65626	23	.91840	42	.67012	23	.94409	42	51	
52	.65649	23	.91883	42	.67034	22	.94452	43	52	
53	.65672	23	.91926	43	.67057	23	.94495	42	53	
54	.65696	23	.91968	42	.67080	23	.94538	43	54	
55	9.65719	23	9.92011	42	9.67103	23	9.94581	42	55	
56	.65742	23	.92054	42	.67126	23	.94624	43	56	
57	.65765	23	.92096	42	.67149	22	.94667	42	57	
58	.65789	23	.92139	43	.67171	23	.94710	43	58	
59	.65812	23	.92182	42	.67194	22	.94753	42	59	
60	9.65835	23	9.92224	42	9.67217	22	9.94796	43	60	
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.

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40	23	22
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TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

58°

59°

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

60°

61°

60°				61°				P. P.			
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'	P. P.
0	9.69897	22	10.00000	44	0	9.71197	21	10.02639	44	0	
1	.69919	21	.00044	43	1	.71218	21	.02684	44	1	
2	.69940	22	.00087	44	2	.71239	21	.02728	44	2	
3	.69962	22	.00131	43	3	.71261	21	.02772	44	3	
4	.69984	22	.00175	43	4	.71282	21	.02816	44	4	
5	9.70006	22	10.00219	44	5	9.71304	21	10.02861	44	5	
6	.70028	21	.00262	43	6	.71325	21	.02905	44	6	
7	.70050	22	.00306	44	7	.71346	21	.02949	44	7	
8	.70072	22	.00350	44	8	.71368	21	.02994	44	8	
9	.70093	21	.00394	43	9	.71389	21	.03038	44	9	6 45 44
10	9.70115	22	10.00438	44	10	9.71411	21	10.03082	44	10	7 4.5 4.4
11	.70137	21	.00482	44	11	.71432	21	.03127	44	11	8 5.2 5.2
12	.70159	22	.00525	43	12	.71453	21	.03171	44	12	9 6.0 5.9
13	.70181	22	.00569	44	13	.71475	21	.03215	44	13	10 6.7 6.7
14	.70202	21	.00613	44	14	.71496	21	.03260	44	14	20 7.5 7.4
15	9.70224	22	10.00657	44	15	9.71517	21	10.03304	44	15	30 15.0 14.5
16	.70246	21	.00701	43	16	.71539	21	.03348	44	16	40 22.5 22.2
17	.70268	22	.00745	44	17	.71560	21	.03393	44	17	50 30.0 29.6
18	.70289	21	.00789	44	18	.71581	21	.03437	44	18	
19	.70311	22	.00833	44	19	.71603	21	.03481	44	19	
20	9.70333	21	10.00876	43	20	9.71624	21	10.03526	44	20	
21	.70355	22	.00920	44	21	.71645	21	.03570	44	21	6 44 43
22	.70376	21	.00964	44	22	.71667	21	.03615	44	22	7 4.4 4.3
23	.70398	22	.01008	44	23	.71688	21	.03659	44	23	8 5.1 5.1
24	.70420	21	.01052	44	24	.71709	21	.03704	44	24	9 5.8 5.3
25	9.70441	22	10.01096	41	25	9.71730	21	10.03748	44	25	10 6.6 6.5
26	.70463	21	.01140	44	26	.71752	21	.03793	44	26	20 7.3 7.2
27	.70485	22	.01184	44	27	.71773	21	.03837	44	27	30 14.6 14.5
28	.70507	21	.01228	44	28	.71794	21	.03881	44	28	40 22.0 21.7
29	.70528	22	.01272	44	29	.71815	21	.03926	44	29	50 29.3 29.0
30	9.70550	21	10.01316	44	30	9.71837	21	10.03970	44	30	
31	.70572	22	.01360	44	31	.71858	21	.04015	44	31	
32	.70593	21	.01404	44	32	.71879	21	.04059	44	32	
33	.70615	22	.01448	44	33	.71900	21	.04104	45	33	6 22 21
34	.70636	21	.01492	44	34	.71922	21	.04149	44	34	7 2.2 2.1
35	9.70658	22	10.01536	44	35	9.71943	21	10.04193	44	35	8 2.5 2.5
36	.70680	21	.01580	44	36	.71964	21	.04238	44	36	9 2.9 2.6
37	.70701	22	.01624	44	37	.71985	21	.04282	44	37	10 3.3 3.2
38	.70723	21	.01668	44	38	.72006	21	.04327	44	38	20 3.6 3.6
39	.70745	22	.01712	44	39	.72028	21	.04371	44	39	30 7.3 7.1
40	9.70766	21	10.01756	44	40	9.72049	21	10.04416	44	40	40 11.0 10.7
41	.70788	22	.01800	44	41	.72070	21	.04461	45	41	50 14.6 14.3
42	.70809	21	.01844	44	42	.72091	21	.04505	44	42	
43	.70831	22	.01889	44	43	.72112	21	.04550	44	43	
44	.70852	21	.01933	44	44	.72133	21	.04594	44	44	
45	9.70874	22	10.01977	44	45	9.72154	21	10.04639	45	45	
46	.70896	21	.02021	44	46	.72176	21	.04684	44	46	6 21 21
47	.70917	22	.02065	44	47	.72197	21	.04728	44	47	7 2.1 2.1
48	.70939	21	.02109	44	48	.72218	21	.04773	44	48	8 2.4 2.8
49	.70960	22	.02153	44	49	.72239	21	.04818	45	49	9 2.8 3.1
50	9.70982	21	10.02197	44	50	9.72260	21	10.04862	44	50	10 3.1 3.5
51	.71003	22	.02242	44	51	.72281	21	.04907	45	51	20 3.5 7.0
52	.71025	21	.02286	44	52	.72302	21	.04952	44	52	30 7.0 10.5
53	.71046	22	.02330	44	53	.72323	21	.04996	44	53	40 14.0 14.3
54	.71068	21	.02374	44	54	.72344	21	.05041	45	54	50 17.5 17.9
55	9.71089	22	10.02418	44	55	9.72365	21	10.05086	44	55	
56	.71111	21	.02463	44	56	.72386	21	.05131	45	56	
57	.71132	22	.02507	44	57	.72408	21	.05175	44	57	
58	.71154	21	.02551	44	58	.72429	21	.05220	45	58	
59	.71175	22	.02595	44	59	.72450	21	.05265	44	59	
60	9.71197	21	10.02639	44	60	9.72471	21	10.05310	45	60	
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'	P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

62°				63°									
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D		P. P.		
0	9.72471	21	10.05310	44	9.73720	20	10.08015	45	0				
1	.72492	21	.05354	45	.73740	20	.08061	45	1				
2	.72513	21	.05399	45	.73761	21	.08106	45	2				
3	.72534	21	.05444	44	.73782	20	.08151	45	3				
4	.72555	21	.05489	45	.73802	20	.08197	45	4				
5	9.72576	21	10.05534	45	9.73823	20	10.08242	45	5			46	46
6	.72597	21	.05579	44	.73843	20	.08288	45	6	6	4.6	4.6	
7	.72618	21	.05623	45	.73864	20	.08333	45	7	7	5.4	5.3	
8	.72639	21	.05668	45	.73884	20	.08379	45	8	8	6.2	6.1	
9	.72660	21	.05713	45	.73905	21	.08424	45	9	9	7.0	6.9	
10	9.72681	21	10.05758	45	9.73926	20	10.08470	45	10	10	7.7	7.6	
11	.72701	20	.05803	44	.73946	20	.08515	45	11	20	15.5	15.3	
12	.72722	21	.05848	45	.73967	20	.08561	45	12	30	23.2	23.0	
13	.72743	21	.05893	45	.73987	20	.08606	45	13	40	31.0	30.6	
14	.72764	21	.05938	45	.74008	20	.08652	45	14	50	38.7	38.3	
15	9.72785	21	10.05983	45	9.74028	20	10.08697	45	15				
16	.72806	21	.06028	45	.74049	20	.08743	46	16	6	4.3	4.5	45
17	.72827	21	.06072	44	.74069	20	.08789	45	17	7	5.3	5.2	
18	.72848	20	.06117	45	.74090	20	.08834	45	18	8	6.0	6.0	
19	.72869	21	.06162	45	.74110	20	.08880	45	19	9	6.8	6.7	
20	9.72890	21	10.06207	45	9.74131	20	10.08926	46	20	10	7.6	7.5	
21	.72911	21	.06252	45	.74151	20	.08971	45	21	20	15.1	15.0	
22	.72931	20	.06297	45	.74172	20	.09017	45	22	30	22.7	22.5	
23	.72952	21	.06342	45	.74192	20	.09062	45	23	40	30.3	30.0	
24	.72973	21	.06387	45	.74213	20	.09108	46	24	50	37.9	37.5	
25	9.72994	21	10.06432	45	9.74233	20	10.09154	45	25				
26	.73015	20	.06477	45	.74254	20	.09200	46	26				
27	.73036	21	.06522	45	.74274	20	.09245	45	27				44
28	.73057	21	.06568	45	.74294	20	.09291	45	28	6	4.4	4.4	
29	.73077	20	.06613	45	.74315	20	.09337	46	29	7	5.2	5.2	
30	9.73098	21	10.06658	45	9.74335	20	10.09382	45	30	8	5.9	5.9	
31	.73119	21	.06703	45	.74356	20	.09428	46	31	9	6.7	6.7	
32	.73140	20	.06748	45	.74376	20	.09474	46	32	10	7.4	7.4	
33	.73161	21	.06793	45	.74396	20	.09520	45	33	20	14.8	14.8	
34	.73181	20	.06838	45	.74417	20	.09566	46	34	30	22.2	22.2	
35	9.73202	21	10.06883	45	9.74437	20	10.09611	45	35	40	29.6	29.6	
36	.73223	21	.06928	45	.74458	20	.09657	45	36	50	37.1	37.1	
37	.73244	20	.06974	45	.74478	20	.09703	46	37				
38	.73265	21	.07019	45	.74498	20	.09749	45	38				
39	.73285	20	.07064	45	.74519	20	.09795	46	39				
40	9.73306	21	10.07109	45	9.74539	20	10.09841	45	40	6	2.1	2.0	20
41	.73327	20	.07154	45	.74559	20	.09886	46	41	7	2.4	2.4	
42	.73348	21	.07200	45	.74580	20	.09932	45	42	8	2.8	2.7	
43	.73368	20	.07245	45	.74600	20	.09978	46	43	9	3.1	3.1	
44	.73389	21	.07290	45	.74620	20	.10024	46	44	10	3.5	3.4	
45	9.73410	20	10.07335	45	9.74641	20	10.10070	45	45	20	7.0	6.8	
46	.73430	21	.07380	45	.74661	20	.10116	46	46	30	10.5	10.2	
47	.73451	20	.07426	45	.74681	20	.10162	46	47	40	14.0	13.6	
48	.73472	21	.07471	45	.74702	20	.10208	45	48	50	17.5	17.1	
49	.73493	20	.07516	45	.74722	20	.10254	46	49				
50	9.73513	20	10.07562	45	9.74742	20	10.10300	45	50				20
51	.73534	21	.07607	45	.74762	20	.10346	46	51	6	2.0	2.0	
52	.73555	20	.07652	45	.74783	20	.10392	46	52	7	2.3	2.3	
53	.73575	20	.07697	45	.74803	20	.10438	46	53	8	2.6	2.6	
54	.73596	20	.07743	45	.74823	20	.10484	46	54	9	3.0	3.0	
55	9.73617	21	10.07788	45	9.74844	20	10.10530	45	55	10	3.3	3.3	
56	.73637	20	.07834	45	.74864	20	.10576	46	56	20	6.6	6.6	
57	.73658	20	.07879	45	.74884	20	.10622	46	57	30	10.0	10.0	
58	.73679	21	.07924	45	.74904	20	.10668	46	58	40	13.3	13.3	
59	.73699	20	.07970	45	.74924	20	.10714	46	59	50	16.6	16.6	
60	9.73720		10.08015		9.74945		10.10760		60				
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D			P. P.		

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.74945	20	10.10760	46	9.76146	19	10.13551	47	0		
1	.74965	20	.10807	46	.76166	20	.13598	47	1		
2	.74985	20	.10853	46	.76186	20	.13645	47	2		
3	.75005	20	.10899	46	.76206	20	.13692	47	3		
4	.75026	20	.10945	46	.76225	19	.13739	47	4		
5	9.75046	20	10.10991	46	9.76245	20	10.13786	47	5		48
6	.75066	20	.11037	46	.76265	19	.13833	47	6	6	4.8
7	.75086	20	.11084	46	.76285	20	.13880	47	7	7	5.6
8	.75106	20	.11130	46	.76304	19	.13927	47	8	8	6.4
9	.75126	20	.11176	46	.76324	20	.13974	47	9	9	7.2
10	9.75147	20	10.11222	46	9.76344	20	10.14021	47	10	10	8.0
11	.75167	20	.11269	46	.76364	19	.14068	47	11	20	16.0
12	.75187	20	.11315	46	.76384	20	.14115	47	12	30	24.0
13	.75207	20	.11361	46	.76403	19	.14162	47	13	40	32.0
14	.75227	20	.11407	46	.76423	20	.14210	47	14	50	40.0
15	9.75247	20	10.11454	46	9.76443	19	10.14257	47	15		
16	.75267	20	.11500	46	.76463	20	.14304	47	16		47
17	.75287	20	.11546	46	.76482	19	.14351	47	17	6	4.7
18	.75308	20	.11593	46	.76502	19	.14398	47	18	7	5.5
19	.75328	20	.11639	46	.76522	20	.14445	47	19	8	6.3
20	9.75348	20	10.11685	46	9.76541	19	10.14493	47	20	9	7.0
21	.75368	20	.11732	46	.76561	20	.14540	47	21	10	7.8
22	.75388	20	.11778	46	.76581	19	.14587	47	22	20	15.6
23	.75408	20	.11825	46	.76600	19	.14634	47	23	30	23.5
24	.75428	20	.11871	46	.76620	20	.14682	47	24	40	31.4
25	9.75448	20	10.11917	46	9.76640	19	10.14729	47	25	50	39.4
26	.75468	20	.11964	46	.76659	19	.14776	47	26		
27	.75488	20	.12010	46	.76679	20	.14823	47	27		46
28	.75508	20	.12057	46	.76699	19	.14871	47	28	6	4.6
29	.75528	20	.12103	46	.76718	19	.14918	47	29	7	5.3
30	9.75548	20	10.12150	46	9.76738	20	10.14965	47	30	8	6.1
31	.75568	20	.12196	46	.76758	19	.15013	47	31	9	6.9
32	.75588	20	.12243	46	.76777	19	.15060	47	32	10	7.7
33	.75608	20	.12289	46	.76797	19	.15108	47	33	20	15.5
34	.75628	20	.12336	46	.76817	20	.15155	47	34	30	23.0
35	9.75648	20	10.12383	47	9.76836	19	10.15202	47	35	40	30.7
36	.75668	20	.12429	46	.76856	19	.15250	47	36	50	38.3
37	.75688	20	.12476	46	.76875	19	.15297	47	37		
38	.75708	20	.12522	46	.76895	20	.15345	47	38		26
39	.75728	20	.12569	46	.76915	19	.15392	47	39	6	2.6
40	9.75748	20	10.12616	47	9.76934	19	10.15440	47	40	7	3.4
41	.75768	20	.12662	46	.76954	19	.15487	47	41	8	4.2
42	.75788	20	.12709	46	.76973	19	.15535	47	42	9	5.0
43	.75808	20	.12756	47	.76993	19	.15582	47	43	10	5.8
44	.75828	19	.12802	46	.77012	19	.15630	47	44	20	10.5
45	9.75848	20	10.12849	46	9.77032	20	10.15678	48	45	30	18.1
46	.75868	20	.12896	47	.77052	19	.15725	47	46	40	26.2
47	.75888	20	.12942	46	.77071	19	.15773	47	47	50	34.3
48	.75908	20	.12989	47	.77091	19	.15820	47	48		
49	.75928	20	.13036	46	.77110	19	.15868	47	49		19
50	9.75947	19	10.13083	47	9.77130	19	10.15916	47	50	6	1.9
51	.75967	20	.13130	47	.77149	19	.15963	47	51	7	2.7
52	.75987	20	.13176	46	.77169	19	.16011	47	52	8	3.5
53	.76007	20	.13223	47	.77188	19	.16059	47	53	9	4.3
54	.76027	19	.13270	46	.77208	19	.16106	47	54	10	5.1
55	9.76047	20	10.13317	47	9.77227	19	10.16154	48	55	20	13.0
56	.76067	20	.13364	47	.77247	19	.16202	47	56	30	21.1
57	.76087	20	.13411	47	.77266	19	.16250	48	57	40	29.2
58	.76106	19	.13457	46	.77286	19	.16298	48	58	50	37.3
59	.76126	20	.13504	47	.77305	19	.16345	47	59		
60	9.76146	20	10.13551	47	9.77325	19	10.16393	48	60		
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.	

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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66°					67°					P. P.		
'	Log. Vers.	D	Log. Exsec.	D	'	Log. Vers.	D	Log. Exsec.	D	'		
0	9.77325	19	10.16393	48	0	9.78481	19	10.19293	49	0		
1	.77344	19	.16441	47	1	.78500	19	.19342	49	1		
2	.77363	19	.16489	47	2	.78519	19	.19391	48	2		
3	.77383	19	.16537	48	3	.78538	19	.19439	48	3		
4	.77402	19	.16585	48	4	.78557	19	.19488	49	4		
5	9.77422	19	10.16633	48	5	9.78576	19	10.19537	49	5	6	50
6	.77441	19	.16680	47	6	.78595	19	.19586	49	6	7	5.0
7	.77461	19	.16728	48	7	.78614	19	.19635	49	7	8	5.8
8	.77480	19	.16776	48	8	.78633	19	.19684	49	8	9	6.6
9	.77499	19	.16824	48	9	.78652	19	.19733	49	9	10	7.5
10	9.77519	19	10.16872	48	10	9.78671	19	10.19782	49	10	20	8.3
11	.77538	19	.16920	48	11	.78690	19	.19831	49	11	30	16.6
12	.77557	19	.16968	48	12	.78709	19	.19880	49	12	40	25.0
13	.77577	19	.17016	48	13	.78728	19	.19929	49	13	50	33.3
14	.77596	19	.17064	48	14	.78747	19	.19979	49	14		41.6
15	9.77616	19	10.17112	48	15	9.78766	19	10.20028	49	15		
16	.77635	19	.17160	48	16	.78785	19	.20077	49	16	6	49
17	.77654	19	.17209	48	17	.78804	19	.20126	49	17	7	4.9
18	.77674	19	.17257	48	18	.78823	19	.20175	49	18	8	5.7
19	.77693	19	.17305	48	19	.78842	19	.20224	49	19	9	6.5
20	9.77712	19	10.17353	48	20	9.78861	19	10.20273	49	20	10	7.3
21	.77732	19	.17401	48	21	.78880	19	.20323	49	21	20	8.1
22	.77751	19	.17449	48	22	.78899	19	.20372	49	22	30	16.3
23	.77770	19	.17498	48	23	.78918	19	.20421	49	23	40	24.5
24	.77790	19	.17546	48	24	.78937	18	.20470	49	24	50	32.6
25	9.77809	19	10.17594	48	25	9.78956	19	10.20520	49	25		
26	.77828	19	.17642	48	26	.78975	19	.20569	49	26	48	
27	.77847	19	.17690	48	27	.78994	19	.20618	49	27	6	4.8
28	.77867	19	.17739	48	28	.79013	19	.20668	49	28	7	5.6
29	.77886	19	.17787	48	29	.79032	19	.20717	49	29	8	6.4
30	9.77905	19	10.17835	48	30	9.79051	19	10.20767	49	30	9	7.2
31	.77925	19	.17884	48	31	.79069	18	.20816	49	31	10	8.0
32	.77944	19	.17932	48	32	.79088	19	.20865	49	32	20	16.0
33	.77963	19	.17980	48	33	.79107	19	.20915	49	33	30	24.0
34	.77982	19	.18029	48	34	.79126	19	.20964	49	34	40	32.0
35	9.78002	19	10.18077	48	35	9.79145	19	10.21014	49	35	50	40.0
36	.78021	19	.18126	48	36	.79164	18	.21063	49	36		
37	.78040	19	.18174	48	37	.79183	19	.21113	49	37	16	
38	.78059	19	.18222	48	38	.79202	19	.21162	49	38	6	1.9
39	.78078	19	.18271	48	39	.79220	18	.21212	50	39	7	2.3
40	9.78098	19	10.18319	48	40	9.79239	19	10.21262	49	40	8	2.6
41	.78117	19	.18368	48	41	.79258	19	.21311	49	41	9	2.9
42	.78136	19	.18416	48	42	.79277	18	.21361	49	42	10	3.2
43	.78155	19	.18465	49	43	.79296	19	.21410	49	43	20	6.5
44	.78174	19	.18514	48	44	.79315	19	.21460	50	44	30	9.7
45	9.78194	19	10.18562	48	45	9.79333	18	10.21510	49	45	40	13.0
46	.78213	19	.18611	48	46	.79352	19	.21560	50	46	50	16.2
47	.78232	19	.18659	48	47	.79371	19	.21609	49	47		
48	.78251	19	.18708	48	48	.79390	18	.21659	50	48	19	
49	.78270	19	.18757	49	49	.79409	19	.21709	49	49	6	1.9
50	9.78289	19	10.18805	48	50	9.79427	18	10.21759	50	50	7	2.2
51	.78309	19	.18854	48	51	.79446	19	.21808	49	51	8	2.5
52	.78328	19	.18903	49	52	.79465	19	.21858	50	52	9	2.8
53	.78347	19	.18951	48	53	.79484	18	.21908	50	53	10	3.1
54	.78366	19	.19000	49	54	.79503	19	.21958	49	54	20	6.1
55	9.78385	19	10.19049	48	55	9.79521	18	10.22008	50	55	30	9.2
56	.78404	19	.19098	49	56	.79540	19	.22058	50	56	40	12.3
57	.78423	19	.19146	48	57	.79559	18	.22108	50	57	50	15.4
58	.78442	19	.19195	49	58	.79578	19	.22158	50	58		
59	.78462	19	.19244	49	59	.79596	18	.22208	50	59		
60	9.78481	19	10.19293	48	60	9.79615	19	10.22258	50	60		

BLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.		
9.79615	18	10.22258	50	9.80728	18	10.25295	51	0	6	53	52
.79634	19	.22308	50	.80747	18	.25347	51	1			
.79653	18	.22358	50	.80765	18	.25398	51	2			
.79671	18	.22408	50	.80783	18	.25449	51	3			
.79690	18	.22458	50	.80802	18	.25501	51	4			
9.79709	19	10.22508	50	9.80820	18	10.25552	51	5	7	5.3	5.1
.79727	18	.22558	50	.80839	18	.25604	51	6	8	6.2	5.1
.79746	19	.22608	50	.80857	18	.25655	51	7	9	7.0	7.0
.79765	18	.22658	50	.80875	18	.25707	51	8	10	7.0	7.0
.79783	18	.22708	50	.80894	18	.25758	51	9	20	8.0	8.0
9.79802	19	10.22759	50	9.80912	18	10.25810	51	10	30	17.0	17.0
.79821	18	.22809	50	.80930	18	.25861	51	11	40	26.0	26.0
.79839	18	.22859	50	.80949	18	.25913	51	12	50	35.0	35.0
.79858	19	.22909	50	.80967	18	.25964	51	13		44.0	43.0
.79877	18	.22960	50	.80985	18	.26016	51	14			
9.79895	18	10.23010	50	9.81003	18	10.26067	51	15	6	5.2	5.1
.79914	18	.23060	50	.81022	18	.26119	52	16	7	6.0	6.0
.79933	19	.23110	50	.81040	18	.26171	51	17	8	6.9	6.6
.79951	18	.23161	50	.81058	18	.26222	51	18	9	7.8	7.4
.79970	18	.23211	50	.81077	18	.26274	52	19	10	8.6	8.0
9.79988	18	10.23262	50	9.81095	18	10.26326	51	20	20	17.3	17.1
.80007	19	.23312	50	.81113	18	.26378	52	21	30	26.0	25.0
.80026	18	.23362	50	.81131	18	.26429	51	22	40	34.6	34.0
.80044	18	.23413	50	.81150	18	.26481	52	23	50	43.3	42.0
.80063	18	.23463	50	.81168	18	.26533	52	24			
9.80081	18	10.23514	50	9.81186	18	10.26585	51	25	6	5.1	5.0
.80100	19	.23564	50	.81204	18	.26637	51	26	7	5.9	5.0
.80119	18	.23615	50	.81223	18	.26689	52	27	8	6.8	6.0
.80137	18	.23666	50	.81241	18	.26741	52	28	9	7.6	7.0
.80156	18	.23716	50	.81259	18	.26793	52	29	10	8.5	8.4
9.80174	18	10.23767	50	9.81277	18	10.26845	51	30	20	17.0	16.0
.80193	18	.23817	50	.81295	18	.26897	52	31	30	25.5	25.0
.80211	18	.23868	51	.81314	18	.26949	52	32	40	34.0	33.0
.80230	18	.23919	50	.81332	18	.27001	52	33	50	42.5	42.0
.80248	18	.23969	50	.81350	18	.27053	52	34			
9.80267	19	10.24020	51	9.81368	18	10.27105	51	35	6	5.0	5.0
.80286	18	.24071	50	.81386	18	.27157	52	36	7	5.8	5.0
.80304	18	.24122	51	.81405	18	.27209	52	37	8	6.6	6.0
.80323	18	.24172	50	.81423	18	.27261	52	38	9	7.5	7.0
.80341	18	.24223	51	.81441	18	.27314	52	39	10	8.4	8.0
9.80360	18	10.24274	51	9.81459	18	10.27366	51	40	20	16.6	16.0
.80378	18	.24325	50	.81477	18	.27418	52	41	30	25.0	25.0
.80397	18	.24376	51	.81495	18	.27470	52	42	40	33.3	33.0
.80415	18	.24427	51	.81513	18	.27523	52	43	50	41.6	41.0
.80434	18	.24478	51	.81532	18	.27575	52	44			
9.80452	18	10.24529	51	9.81550	18	10.22627	51	45	6	1.9	1.8
.80470	18	.24580	51	.81568	18	.27680	52	46	7	2.2	2.1
.80489	18	.24631	51	.81586	18	.27732	52	47	8	2.5	2.4
.80507	18	.24682	51	.81604	18	.27785	52	48	9	2.8	2.6
.80526	18	.24733	51	.81622	18	.27837	52	49	10	3.1	3.1
9.80544	18	10.24784	51	9.81640	18	10.27890	51	50	20	6.3	6.1
.80563	18	.24835	51	.81658	18	.27942	52	51	30	9.5	9.2
.80581	18	.24886	51	.81676	18	.27995	52	52	40	12.6	12.0
.80600	18	.24937	51	.81695	18	.28047	52	53	50	15.8	15.4
.80618	18	.24988	51	.81713	18	.28100	52	54			
9.80636	18	10.25039	51	9.81731	18	10.28152	51	55	6	1.8	1.8
.80655	18	.25090	51	.81749	18	.28205	52	56	7	2.1	2.1
.80673	18	.25142	51	.81767	18	.28258	52	57	8	2.4	2.4
.80692	18	.25193	51	.81785	18	.28310	52	58	9	2.7	2.7
.80710	18	.25244	51	.81803	18	.28363	53	59	10	3.0	3.0
9.80728	18	10.25295	51	9.81821	18	10.28416	52	60	20	6.0	6.0
Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D				P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.81821	18	10.28416	53	9.82894	19	10.31629	54	0	
1	.81839	18	.28469	52	.82911	19	.31684	54	1	
2	.81857	18	.28521	53	.82929	19	.31738	54	2	
3	.81875	18	.28574	53	.82947	18	.31793	54	3	56
4	.81893	18	.28627	53	.82964	19	.31847	54	4	5.6
		18		52		18		54	5	6.5
5	9.81911	18	10.28680	53	9.82982	19	10.31902	54	6	7.4
6	.81929	18	.28733	53	.83000	19	.31956	54	7	8.4
7	.81947	18	.28786	53	.83017	18	.32011	55	8	9.4
8	.81965	18	.28839	53	.83035	19	.32066	55	9	10.4
9	.81983	18	.28892	53	.83053	19	.32120	54	10	11.4
		18		53		19		54	11	12.4
10	9.82001	18	10.28945	53	9.83070	18	10.32175	55	12	13.4
11	.82019	18	.28998	53	.83088	19	.32230	54	13	14.4
12	.82037	18	.29051	53	.83106	19	.32284	55	14	15.4
13	.82055	18	.29104	53	.83123	19	.32339	54	15	16.4
14	.82073	18	.29157	53	.83141	18	.32394	55	16	17.4
		18		53		19		55	17	18.4
15	9.82091	19	10.29210	53	9.83159	19	10.32449	55	18	19.4
16	.82109	18	.29263	53	.83176	19	.32504	54	19	20.4
17	.82127	18	.29316	53	.83194	19	.32558	55	20	21.4
18	.82145	18	.29370	53	.83211	18	.32613	55	21	22.4
19	.82163	18	.29423	53	.83229	19	.32668	55	22	23.4
		18		53		19		55	23	24.4
20	9.82181	18	10.29476	53	9.83247	19	10.32723	55	24	25.4
21	.82199	18	.29529	53	.83264	19	.32778	55	25	26.4
22	.82217	18	.29583	53	.83282	19	.32833	55	26	27.4
23	.82235	18	.29636	53	.83299	18	.32888	55	27	28.4
24	.82252	19	.29689	53	.83317	19	.32944	55	28	29.4
		18		53		19		55	29	30.4
25	9.82270	18	10.29743	53	9.83335	19	10.32999	55	30	31.4
26	.82288	18	.29796	53	.83352	19	.33054	55	31	32.4
27	.82306	18	.29850	53	.83370	19	.33109	55	32	33.4
28	.82324	18	.29903	53	.83387	19	.33164	55	33	34.4
29	.82342	19	.29957	53	.83405	19	.33220	55	34	35.4
		18		53		19		55	35	36.4
30	9.82360	18	10.30010	53	9.83422	19	10.33275	55	36	37.4
31	.82378	18	.30064	53	.83440	18	.33330	55	37	38.4
32	.82396	19	.30117	54	.83458	19	.33385	55	38	39.4
33	.82413	18	.30171	54	.83475	19	.33441	55	39	40.4
34	.82431	18	.30225	53	.83493	19	.33496	55	40	41.4
		18		53		19		55	41	42.4
35	9.82449	19	10.30278	54	9.83510	19	10.33552	55	42	43.4
36	.82467	18	.30332	53	.83528	19	.33607	55	43	44.4
37	.82485	18	.30386	54	.83545	19	.33663	55	44	45.4
38	.82503	19	.30440	53	.83563	19	.33718	55	45	46.4
39	.82520	18	.30493	53	.83580	19	.33774	55	46	47.4
		18		54		19		55	47	48.4
40	9.82538	18	10.30547	53	9.83598	19	10.33829	56	48	49.4
41	.82556	19	.30601	54	.83615	19	.33885	55	49	50.4
42	.82574	18	.30655	54	.83633	19	.33941	55	50	51.4
43	.82592	19	.30709	54	.83650	19	.33996	56	51	52.4
44	.82609	18	.30763	54	.83668	19	.34052	55	52	53.4
		18		54		19		55	53	54.4
45	9.82627	18	10.30817	54	9.83685	19	10.34108	56	54	55.4
46	.82645	19	.30871	54	.83703	19	.34164	56	55	56.4
47	.82663	18	.30925	54	.83720	19	.34220	56	56	57.4
48	.82681	18	.30979	54	.83737	19	.34275	56	57	58.4
49	.82698	19	.31033	54	.83755	19	.34331	56	58	59.4
		18		54		19		56	59	60.4
50	9.82716	19	10.31087	54	9.83772	19	10.34387	56	60	61.4
51	.82734	18	.31141	54	.83790	19	.34443	56	61	62.4
52	.82752	19	.31195	54	.83807	19	.34499	56	62	63.4
53	.82769	18	.31249	54	.83825	19	.34555	56	63	64.4
54	.82787	18	.31303	54	.83843	19	.34611	56	64	65.4
		19		54		19		56	65	66.4
55	9.82805	18	10.31358	54	9.83859	19	10.34667	56	66	67.4
56	.82823	19	.31412	54	.83877	19	.34723	56	67	68.4
57	.82840	18	.31466	54	.83894	19	.34780	56	68	69.4
58	.82858	19	.31521	54	.83912	19	.34836	56	69	70.4
59	.82876	18	.31575	54	.83929	19	.34892	56	70	71.4
		18		54		19		56	71	72.4
60	9.82894		10.31629		9.83946		10.34948		72	73.4
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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73°

		Log. Vers.		D		Log. Exsec.		D				P. P.	
0	9.83946	17	10.34948	56	9.84980	17	10.38387	58	0				
1	.83964	17	.35005	56	.84997	17	.38445	58	1				
2	.83981	17	.35061	56	.85014	17	.38504	58	2				
3	.83999	17	.35117	56	.85031	17	.38562	58	3		61	66	
4	.84016	17	.35174	56	.85049	17	.38621	58	4	6	6.1	6.6	
5	9.84033	17	10.35230	56	9.85066	17	10.38679	58	5	7	7.1	7.6	
6	.84051	17	.35286	56	.85083	17	.38738	58	6	8	8.1	8.6	
7	.84068	17	.35343	56	.85100	17	.38796	58	7	9	9.1	9.6	
8	.84085	17	.35399	56	.85117	17	.38855	59	8	10	10.1	10.6	
9	.84103	17	.35456	57	.85134	17	.38914	58	9	20	20.3	20.7	
10	9.84120	17	10.35513	56	9.85151	17	10.38973	59	10	30	30.5	30.9	
11	.84137	17	.35569	56	.85168	17	.39031	58	11	40	40.6	40.9	
12	.84155	17	.35626	56	.85185	17	.39090	59	12	50	50.8	50.9	
13	.84172	17	.35683	57	.85202	17	.39149	59	13				
14	.84189	17	.35739	56	.85219	17	.39208	58	14	6	6.0	5.9	
15	9.84207	17	10.35796	57	9.85236	17	10.39267	59	15	7	7.0	6.9	
16	.84224	17	.35853	56	.85253	17	.39326	59	16	8	8.0	7.9	
17	.84241	17	.35910	57	.85270	17	.39385	59	17	9	9.0	8.9	
18	.84259	17	.35967	57	.85287	17	.39444	59	18	10	10.0	9.9	
19	.84276	17	.36023	56	.85304	17	.39503	59	19	20	20.0	19.9	
20	9.84293	17	10.36080	57	9.85321	17	10.39562	59	20	30	30.0	29.9	
21	.84310	17	.36137	57	.85338	17	.39621	59	21	40	40.0	39.9	
22	.84328	17	.36194	57	.85355	17	.39681	59	22	50	50.0	49.9	
23	.84345	17	.36251	57	.85372	17	.39740	59	23				
24	.84362	17	.36308	57	.85389	17	.39799	59	24	6	5.9	5.8	
25	9.84380	17	10.36366	57	9.85405	16	10.39859	59	25	7	6.9	6.8	
26	.84397	17	.36423	57	.85422	17	.39918	59	26	8	7.9	7.8	
27	.84414	17	.36480	57	.85439	17	.39977	59	27	9	8.9	8.8	
28	.84431	17	.36537	57	.85456	17	.40037	59	28	10	9.9	9.7	
29	.84449	17	.36594	57	.85473	17	.40096	59	29	20	19.6	19.5	
30	9.84466	17	10.36652	57	9.85490	17	10.40156	59	30	30	29.5	29.4	
31	.84483	17	.36709	57	.85507	17	.40216	60	31	40	39.3	39.0	
32	.84500	17	.36766	57	.85524	16	.40275	59	32	50	49.1	48.5	
33	.84517	17	.36824	57	.85541	17	.40335	59	33				
34	.84535	17	.36881	57	.85558	17	.40395	60	34	6	5.8	5.7	
35	9.84552	17	10.36938	57	9.85575	17	10.40454	59	35	7	6.7	6.7	
36	.84569	17	.36996	57	.85592	17	.40514	60	36	8	7.7	7.6	
37	.84586	17	.37054	58	.85608	17	.40574	59	37	9	8.7	8.6	
38	.84603	17	.37111	57	.85625	17	.40634	60	38	10	9.6	9.6	
39	.84620	17	.37169	57	.85642	17	.40694	60	39	20	19.3	19.2	
40	9.84638	17	10.37226	57	9.85659	17	10.40754	60	40	30	29.0	28.9	
41	.84655	17	.37284	57	.85676	16	.40814	59	41	40	38.6	38.3	
42	.84672	17	.37342	58	.85693	17	.40874	60	42	50	48.3	47.9	
43	.84689	17	.37399	57	.85710	17	.40934	60	43				
44	.84706	17	.37457	58	.85726	16	.40994	60	44	6	5.7	5.6	
45	9.84724	17	10.37513	58	9.85743	17	10.41054	60	45	7	6.6	6.6	
46	.84741	17	.37573	57	.85760	17	.41114	60	46	8	7.6	7.5	
47	.84758	17	.37631	58	.85777	17	.41174	60	47	9	8.5	8.5	
48	.84775	17	.37689	58	.85794	17	.41235	60	48	10	9.5	9.4	
49	.84792	17	.37747	58	.85811	17	.41295	60	49	20	19.0	18.9	
50	9.84809	17	10.37805	58	9.85827	16	10.41355	60	50	30	28.5	28.4	
51	.84826	17	.37863	58	.85844	17	.41416	60	51	40	38.0	37.7	
52	.84844	17	.37921	58	.85861	17	.41476	60	52	50	47.5	47.1	
53	.84861	17	.37979	58	.85878	16	.41537	60	53				
54	.84878	17	.38037	58	.85895	17	.41597	60	54	6	1.7	1.6	
55	9.84895	17	10.38093	58	9.85911	16	10.41658	60	55	7	2.0	2.0	
56	.84912	17	.38153	58	.85928	17	.41719	61	56	8	2.3	2.2	
57	.84929	17	.38212	58	.85945	17	.41779	60	57	9	2.6	2.5	
58	.84946	17	.38270	58	.85962	16	.41840	60	58	10	2.9	2.8	
59	.84963	17	.38328	58	.85979	17	.41901	61	59	20	2.9	2.9	
60	9.84980	17	10.38387	58	9.85993	16	10.41962	61	60	30	3.2	3.1	
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D			P. P.		

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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75°

		Log. Vers.	D			Log. Exsec.	D			Log. Vers.	D			Log. Exsec.	D
0		9.85995				10.41962				9.86992				10.45693	
1		.86012	17			.42022	66			.87009	16			.45756	63
2		.86029	16			.42083	61			.87025	16			.45820	63
3		.86046	17			.42144	61			.87042	16			.45884	64
4		.86062	16			.42205	61			.87058	16			.45947	63
5		9.86079	17			10.42266	61			9.87074	16			10.46011	64
6		.86096	16			.42327	61			.87091	16			.46075	64
7		.86113	17			.42388	61			.87107	16			.46139	64
8		.86129	16			.42450	61			.87124	16			.46203	64
9		.86146	17			.42511	61			.87140	16			.46267	64
10		9.86163	16			10.42572	61			9.87157	16			10.46331	64
11		.86179	16			.42633	61			.87173	16			.46395	64
12		.86196	17			.42695	61			.87189	16			.46460	64
13		.86213	16			.42756	61			.87206	16			.46524	64
14		.86230	17			.42817	61			.87222	16			.46588	64
15		9.86246	16			10.42879	61			9.87239	16			10.46652	64
16		.86263	16			.42940	61			.87255	16			.46717	64
17		.86280	17			.43002	61			.87271	16			.46781	64
18		.86296	16			.43063	62			.87288	16			.46846	64
19		.86313	16			.43125	61			.87304	16			.46910	64
20		9.86330	17			10.43187	61			9.87320	16			10.46975	64
21		.86346	16			.43249	62			.87337	16			.47040	65
22		.86363	16			.43310	61			.87353	16			.47104	64
23		.86380	17			.43372	62			.87370	16			.47169	65
24		.86396	16			.43434	61			.87386	16			.47234	64
25		9.86413	16			10.43496	62			9.87402	16			10.47299	65
26		.86430	17			.43558	62			.87419	16			.47364	65
27		.86446	16			.43620	62			.87435	16			.47429	65
28		.86463	16			.43682	62			.87451	16			.47494	65
29		.86479	16			.43744	62			.87468	16			.47559	65
30		9.86496	17			10.43806	62			9.87484	16			10.47624	65
31		.86513	16			.43868	62			.87500	16			.47689	65
32		.86529	16			.43931	62			.87516	16			.47754	65
33		.86546	16			.43993	62			.87533	16			.47820	65
34		.86562	16			.44055	62			.87549	16			.47885	65
35		9.86579	17			10.44118	62			9.87565	16			10.47950	65
36		.86596	16			.44180	62			.87582	16			.48016	65
37		.86612	16			.44242	62			.87598	16			.48081	65
38		.86629	16			.44305	63			.87614	16			.48147	66
39		.86645	16			.44368	62			.87631	16			.48213	65
40		9.86662	16			10.44430	62			9.87647	16			10.48278	65
41		.86678	16			.44493	62			.87663	16			.48344	66
42		.86695	17			.44556	63			.87679	16			.48410	66
43		.86712	16			.44618	62			.87696	16			.48476	66
44		.86728	16			.44681	63			.87712	16			.48542	66
45		9.86745	16			10.44744	62			9.87728	16			10.48607	65
46		.86761	16			.44807	63			.87744	16			.48674	66
47		.86778	16			.44870	63			.87761	16			.48740	66
48		.86794	16			.44933	63			.87777	16			.48806	66
49		.86811	16			.44996	63			.87793	16			.48872	66
50		9.86827	16			10.45059	63			9.87809	16			10.48938	66
51		.86844	16			.45122	63			.87825	16			.49004	66
52		.86860	16			.45185	63			.87842	16			.49071	66
53		.86877	16			.45248	63			.87858	16			.49137	66
54		.86893	16			.45312	63			.87874	16			.49204	66
55		9.86910	16			10.45375	63			9.87890	16			10.49270	66
56		.86926	16			.45439	63			.87906	16			.49337	66
57		.86943	16			.45502	63			.87923	16			.49403	67
58		.86959	16			.45565	63			.87939	16			.49470	66
59		.86976	16			.45629	63			.87955	16			.49537	67
60		9.86992	16			10.45693	64			9.87971	16			10.49604	67
		Log. Vers.	D			Log. Exsec.	D			Log. Vers.	D			Log. Exsec.	D

P. P.			
	67	68	66
6	6.7	6.6	6.6
7	7.8	7.7	7.7
8	8.0	8.8	8.8
9	10.0	10.0	9.9
10	11.1	11.1	11.0
20	22.3	22.1	22.0
30	33.5	33.2	33.0
40	44.6	44.3	44.0
50	55.8	55.4	55.0

	65	65	64
6	6.5	6.5	6.4
7	7.6	7.6	7.5
8	8.7	8.6	8.6
9	9.8	9.7	9.7
10	10.9	10.8	10.7
20	21.8	21.6	21.5
30	32.7	32.5	32.2
40	43.6	43.3	43.0
50	54.6	54.1	53.7

	64	63	63
6	6.4	6.3	6.3
7	7.4	7.4	7.3
8	8.5	8.4	8.4
9	9.6	9.5	9.4
10	10.6	10.6	10.5
20	21.3	21.1	21.0
30	32.0	31.7	31.5
40	42.6	42.3	42.0
50	53.3	52.9	52.5

	62	62	61
6	6.2	6.2	6.1
7	7.3	7.2	7.2
8	8.3	8.2	8.2
9	9.4	9.3	9.2
10	10.4	10.3	10.2
20	20.8	20.6	20.5
30	31.2	31.0	30.7
40	41.6	41.3	41.0
50	52.1	51.6	51.2

	61	60
6	6.1	6.0
7	7.1	7.0
8	8.1	8.0
9	9.1	9.1
10	10.1	10.1
20	20.3	20.1
30	30.5	30.3
40	40.6	40.3
50	50.8	50.4

	17	16	16
6	1.7	1.6	1.6
7	2.0	1.9	1.8
8	2.2	2.2	2.1
9	2.5	2.5	2.4
10	2.8	2.7	2.6
20	5.6	5.5	5.3
30	8.5	8.2	8.0
40	11.3	11.0	10.6
50	14.1	13.7	13.3

| P. P. | | | |

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

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												P. P.			
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D						
0	9.87971	16	10.49604	66	9.88933	16	10.53724	70	0						
1	.87987	16	.49670	67	.88949	15	.53794	71	1						
2	.88003	16	.49737	67	.88964	16	.53865	70	2						
3	.88020	16	.49804	67	.88980	16	.53936	71	3						
4	.88036	16	.49871	67	.88996	16	.54007	71	4						
5	9.88052	16	10.49939	67	9.89012	16	10.54078	71	5			75	74	73	
6	.88068	16	.50006	67	.89028	15	.54149	71	6	6	7.5	7.4	7.3		
7	.88084	16	.50073	67	.89044	16	.54220	71	7	7	8.7	8.6	8.5		
8	.88100	16	.50140	67	.89060	16	.54291	71	8	8	10.0	9.8	9.7		
9	.88116	16	.50208	67	.89075	15	.54362	71	9	9	11.2	11.1	11.0		
10	9.88133	16	10.50275	67	9.89091	16	10.54433	71	10	10	12.5	12.3	12.1		
11	.88149	16	.50342	67	.89107	16	.54505	71	11	20	25.0	24.6	24.3		
12	.88165	16	.50410	67	.89123	15	.54576	71	12	30	37.5	37.0	36.5		
13	.88181	16	.50477	68	.89139	16	.54647	72	13	40	50.0	49.3	48.6		
14	.88197	16	.50545	67	.89155	16	.54719	71	14	50	62.5	61.6	60.8		
15	9.88213	16	10.50613	68	9.89170	15	10.54791	71	15						
16	.88229	16	.50681	67	.89186	16	.54862	71	16			72	71	70	
17	.88245	16	.50748	67	.89202	15	.54934	72	17	6	7.2	7.1	7.0		
18	.88261	16	.50816	68	.89218	16	.55006	71	18	7	8.4	8.3	8.2		
19	.88277	16	.50884	68	.89234	16	.55078	72	19	8	9.6	9.4	9.4		
20	9.88294	16	10.50952	68	9.89249	15	10.55150	72	20	9	10.8	10.6	10.6		
21	.88310	16	.51020	68	.89265	16	.55222	72	21	10	12.0	11.8	11.7		
22	.88326	16	.51088	68	.89281	15	.55294	72	22	20	24.0	23.6	23.3		
23	.88342	16	.51157	68	.89297	16	.55366	72	23	30	36.0	35.5	35.2		
24	.88358	16	.51225	68	.89312	15	.55438	72	24	40	48.0	47.3	47.0		
25	9.88374	16	10.51293	68	9.89328	16	10.55511	72	25	50	60.0	59.2	58.7		
26	.88390	16	.51361	68	.89344	15	.55583	72	26						
27	.88406	16	.51430	68	.89360	16	.55655	72	27			69	68	67	
28	.88422	16	.51498	68	.89376	15	.55728	73	28	6	6.9	6.8	6.7		
29	.88438	16	.51567	68	.89391	16	.55801	72	29	7	8.0	7.9	7.8		
30	9.88454	16	10.51636	69	9.89407	15	10.55873	72	30	8	9.2	9.0	8.9		
31	.88470	16	.51704	68	.89423	16	.55946	73	31	9	10.3	10.2	10.0		
32	.88486	16	.51773	68	.89438	15	.56019	72	32	10	11.5	11.3	11.1		
33	.88502	16	.51842	69	.89454	16	.56092	73	33	20	23.0	22.6	22.3		
34	.88518	16	.51911	69	.89470	15	.56165	73	34	30	34.5	34.0	33.5		
35	9.88534	16	10.51980	69	9.89486	16	10.56238	73	35	40	46.0	45.3	44.7		
36	.88550	16	.52049	69	.89501	15	.56311	73	36	50	57.5	56.6	55.8		
37	.88566	16	.52118	69	.89517	16	.56384	73	37						
38	.88582	16	.52187	69	.89533	15	.56457	73	38						
39	.88598	16	.52256	69	.89548	15	.56531	73	39			66	65	64	
40	9.88614	16	10.52325	69	9.89564	16	10.56604	73	40	6	6.6				
41	.88630	16	.52394	69	.89580	15	.56678	73	41	7	7.7				
42	.88646	16	.52464	69	.89596	16	.56751	73	42	8	8.8				
43	.88662	15	.52533	69	.89611	15	.56825	74	43	9	9.9				
44	.88678	16	.52603	69	.89627	15	.56899	73	44	10	11.0				
45	9.88694	16	10.52672	69	9.89643	16	10.56973	74	45	20	22.0				
46	.88710	16	.52742	70	.89658	15	.57047	74	46	30	33.0				
47	.88726	16	.52812	69	.89674	16	.57120	73	47	40	44.0				
48	.88742	16	.52881	69	.89690	15	.57195	74	48	50	55.0				
49	.88758	16	.52951	70	.89705	15	.57269	74	49						
50	9.88774	16	10.53021	70	9.89721	15	10.57343	74	50			18	16	15	
51	.88790	16	.53091	70	.89737	16	.57417	74	51	6	1.6	1.6	1.5		
52	.88805	15	.53161	70	.89752	15	.57491	74	52	7	1.9	1.8	1.7		
53	.88821	16	.53231	70	.89768	15	.57566	74	53	8	2.2	2.1	2.0		
54	.88837	16	.53301	70	.89783	15	.57640	74	54	9	2.5	2.4	2.3		
55	9.88853	16	10.53372	70	9.89799	16	10.57715	75	55	10	2.7	2.6	2.5		
56	.88869	16	.53442	70	.89815	15	.57790	74	56	20	5.5	5.3	5.1		
57	.88885	15	.53512	70	.89830	15	.57864	74	57	30	8.2	8.0	7.7		
58	.88901	16	.53583	70	.89846	15	.57939	75	58	40	11.0	10.6	10.3		
59	.88917	16	.53653	70	.89862	16	.58014	75	59	50	13.7	13.3	12.9		
60	9.88933		10.53724		9.89877		10.58089		60						
	Log. Vers.	D	Log. Exsec.	D		Log. Vers.	D	Log. Exsec.	D			P. P.			

	75	74	73
6	7.5	7.4	7.3
7	8.7	8.6	8.5
8	10.0	9.8	9.7
9	11.2	11.1	11.0
10	12.5	12.3	12.1
20	25.0	24.6	24.3
30	37.5	37.0	36.5
40	50.0	49.3	48.7
50	62.5	61.6	60.8

	72	71	70
6	7.2	7.1	7.0
7	8.4	8.3	8.2
8	9.6	9.4	9.4
9	10.8	10.6	10.6
10	12.0	11.8	11.7
20	24.0	23.6	23.3
30	36.0	35.5	35.2
40	48.0	47.3	47.0
50	60.0	59.1	58.7

	69	68	67
6	6.9	6.8	6.7
7	8.0	7.9	7.8
8	9.2	9.0	8.9
9	10.3	10.2	10.1
10	11.5	11.3	11.1
20	23.0	22.6	22.3
30	34.5	34.0	33.5
40	46.0	45.3	44.7
50	57.5	56.6	55.8

	66	65
6	6.6	6.5
7	7.7	7.6
8	8.8	8.7
9	9.9	9.8
10	11.0	10.9
20	22.0	21.8
30	33.0	32.7
40	44.0	43.6
50	55.0	54.5

	16	15
6	1.6	1.5
7	1.9	1.8
8	2.2	2.1
9	2.5	2.4
10	2.7	2.6
20	5.5	5.3
30	8.2	8.0
40	11.0	10.6
50	13.7	13.3

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

78°

79°

										P. P.			
'	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D	'				
0	9.89877	15	10.58089	75	9.90805	15	10.62745	86	0				
1	.89893	15	.58164	75	.90820	15	.62825	86	1				
2	.89908	15	.58239	75	.90835	15	.62906	86	2				
3	.89924	15	.58315	75	.90851	15	.62986	81	3	86	85	84	
4	.89939	15	.58390	75	.90866	15	.63067	86	4	6	8.6	8.5	8.4
5	9.89955	16	10.58465	75	9.90881	15	10.63148	86	5	7	10.0	9.9	9.8
6	.89971	15	.58541	75	.90897	15	.63229	81	6	8	11.4	11.3	11.2
7	.89986	15	.58616	75	.90912	15	.63310	81	7	9	12.9	12.7	12.6
8	.90002	15	.58692	76	.90927	15	.63391	81	8	10	14.3	14.1	14.0
9	.90017	15	.58768	75	.90943	15	.63472	81	9	20	28.6	28.3	28.0
10	9.90033	15	10.58844	76	9.90958	15	10.63553	81	10	30	43.0	42.5	42.0
11	.90048	15	.58920	76	.90973	15	.63634	81	11	40	57.3	56.6	56.0
12	.90064	15	.58995	75	.90988	15	.63716	81	12	50	71.6	70.8	70.0
13	.90080	16	.59072	75	.91004	15	.63797	81	13				
14	.90095	15	.59148	76	.91019	15	.63879	81	14	83	82	81	
15	9.90111	15	10.59224	76	9.91034	15	10.63961	82	15	6	8.3	8.2	8.1
16	.90126	15	.59300	76	.91049	15	.64043	82	16	7	9.7	9.5	9.4
17	.90142	15	.59377	76	.91065	15	.64125	82	17	8	11.0	10.9	10.8
18	.90157	15	.59453	76	.91080	15	.64207	82	18	9	12.4	12.3	12.2
19	.90173	15	.59530	76	.91095	15	.64289	82	19	10	13.8	13.6	13.5
20	9.90188	15	10.59606	76	9.91110	15	10.64371	82	20	20	27.6	27.3	27.0
21	.90204	15	.59683	77	.91126	15	.64453	82	21	30	41.5	41.0	40.5
22	.90219	15	.59760	76	.91141	15	.64536	82	22	40	55.3	54.6	54.0
23	.90235	15	.59837	77	.91156	15	.64618	82	23	50	69.1	68.3	67.5
24	.90250	15	.59914	77	.91171	15	.64701	82	24				
25	9.90266	15	10.59991	77	9.91187	15	10.64784	82	25	80	79	78	
26	.90281	15	.60068	77	.91202	15	.64867	83	26	6	8.0	7.9	7.8
27	.90297	15	.60145	77	.91217	15	.64950	83	27	7	9.3	9.2	9.1
28	.90312	15	.60223	77	.91232	15	.65033	83	28	8	10.6	10.5	10.4
29	.90328	15	.60300	77	.91247	15	.65116	83	29	9	12.0	11.8	11.7
30	9.90343	15	10.60378	77	9.91263	15	10.65199	83	30	10	13.3	13.1	13.0
31	.90359	15	.60455	77	.91278	15	.65283	83	31	20	26.6	26.3	26.0
32	.90374	15	.60533	77	.91293	15	.65366	83	32	30	40.0	39.5	39.0
33	.90389	15	.60611	78	.91308	15	.65450	83	33	40	53.3	52.6	52.0
34	.90405	15	.60688	77	.91323	15	.65534	83	34	50	66.6	65.8	65.0
35	9.90420	15	10.60766	78	9.91338	15	10.65617	83	35				
36	.90436	15	.60844	78	.91354	15	.65701	84	36	77	76	75	
37	.90451	15	.60923	78	.91369	15	.65785	84	37	6	7.7	7.6	7.5
38	.90467	15	.61001	78	.91384	15	.65870	84	38	7	9.0	8.8	8.7
39	.90482	15	.61079	78	.91399	15	.65954	84	39	8	10.2	10.1	10.0
40	9.90497	15	10.61158	78	9.91414	15	10.66038	84	40	9	11.5	11.4	11.2
41	.90513	15	.61236	78	.91429	15	.66123	84	41	10	12.8	12.6	12.5
42	.90528	15	.61315	78	.91445	15	.66207	84	42	20	25.6	25.3	25.0
43	.90544	15	.61393	78	.91460	15	.66292	84	43	30	38.5	38.0	37.5
44	.90559	15	.61472	79	.91475	15	.66377	85	44	40	51.3	50.6	50.0
45	9.90574	15	10.61551	78	9.91490	15	10.66462	85	45	50	64.1	63.3	62.5
46	.90590	15	.61630	79	.91505	15	.66547	85	46				
47	.90605	15	.61709	79	.91520	15	.66632	85	47	8	0.0	0.0	0.0
48	.90621	15	.61788	79	.91535	15	.66717	85	48	7	0.0	0.0	0.0
49	.90636	15	.61867	79	.91550	15	.66803	85	49	8	0.0	0.0	0.0
50	9.90651	15	10.61947	79	9.91565	15	10.66888	85	50	9	0.1	0.1	0.1
51	.90667	15	.62026	79	.91581	15	.66974	85	51	10	0.1	0.1	0.1
52	.90682	15	.62105	79	.91596	15	.67059	85	52	20	0.1	0.1	0.1
53	.90697	15	.62185	80	.91611	15	.67145	86	53	30	0.1	0.1	0.1
54	.90713	15	.62265	79	.91626	15	.67231	86	54	40	0.1	0.1	0.1
55	9.90728	15	10.62345	80	9.91641	15	10.67317	86	55	50	0.1	0.1	0.1
56	.90744	15	.62424	79	.91656	15	.67403	86	56				
57	.90759	15	.62504	80	.91671	15	.67490	86	57	16	15	15	
58	.90774	15	.62585	80	.91686	15	.67576	86	58	6	1.6	1.5	1.5
59	.90790	15	.62665	80	.91701	15	.67663	86	59	7	1.8	1.8	1.7
60	9.90805	15	10.62745	80	9.91716	15	10.67749	86	60	8	2.1	2.0	2.0
										P. P.			

BLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

80°

81°

Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
9.91716	15	10.67749	86	9.92612	14	10.73178	95	0	
.91731	15	.67836	87	.92626	15	.73273	94	1	
.91746	15	.67923	87	.92641	14	.73368	95	2	
.91761	15	.68010	87	.92656	15	.73463	95	3	
.91776	15	.68097	87	.92671	15	.73558	95	4	
9.91791	15	10.68184	87	9.92686	15	10.73653	95	5	
.91807	15	.68272	87	.92700	14	.73748	95	6	
.91822	15	.68359	87	.92715	15	.73844	95	7	
.91837	15	.68447	87	.92730	14	.73940	96	8	
.91852	15	.68534	87	.92745	15	.74035	95	9	
9.91867	15	10.68622	88	9.92759	14	10.74131	96	10	
.91882	15	.68710	88	.92774	15	.74227	96	11	
.91897	15	.68798	88	.92789	14	.74324	96	12	
.91912	15	.68886	88	.92804	15	.74420	96	13	
.91927	15	.68975	88	.92818	14	.74517	96	14	
9.91942	15	10.69063	88	9.92833	15	10.74613	96	15	
.91957	15	.69152	88	.92848	14	.74710	97	16	
.91972	15	.69240	88	.92862	14	.74807	97	17	
.91987	15	.69329	89	.92877	15	.74905	97	18	
.92002	15	.69418	89	.92892	14	.75002	97	19	
9.92016	14	10.69507	89	9.92907	15	10.75099	97	20	
.92031	15	.69596	89	.92921	14	.75197	98	21	
.92046	15	.69586	89	.92936	14	.75295	97	22	
.92061	15	.69773	89	.92951	15	.75393	98	23	
.92076	15	.69865	89	.92965	14	.75491	98	24	
9.92091	15	10.69955	90	9.92980	15	10.75589	98	25	
.92106	15	.70044	89	.92995	14	.75688	98	26	
.92121	15	.70134	90	.93009	14	.75786	98	27	
.92136	15	.70224	90	.93024	15	.75885	99	28	
.92151	14	.70315	90	.93039	14	.75984	99	29	
9.92166	15	10.70405	90	9.93053	14	10.76083	99	30	
.92181	15	.70495	90	.93068	15	.76182	99	31	
.92196	15	.70586	91	.93083	14	.76282	99	32	
.92211	15	.70677	90	.93097	14	.76382	100	33	
.92226	15	.70768	91	.93112	15	.76481	99	34	
9.92240	14	10.70859	91	9.93127	14	10.76581	100	35	
.92255	15	.70950	91	.93141	14	.76681	100	36	
.92270	15	.71041	91	.93156	14	.76782	100	37	
.92285	15	.71133	91	.93171	15	.76882	100	38	
.92300	15	.71224	91	.93185	14	.76983	100	39	
9.92315	14	10.71316	91	9.93200	14	10.77083	100	40	
.92330	15	.71408	92	.93214	14	.77184	101	41	
.92345	15	.71500	92	.93229	15	.77286	101	42	
.92360	15	.71592	92	.93244	14	.77387	101	43	
.92374	14	.71684	92	.93258	14	.77488	101	44	
9.92389	15	10.71776	92	9.93273	14	10.77590	101	45	
.92404	15	.71869	92	.93287	14	.77692	102	46	
.92419	14	.71961	92	.93302	15	.77794	102	47	
.92434	15	.72054	93	.93317	14	.77896	102	48	
.92449	15	.72147	92	.93331	14	.77998	102	49	
9.92463	14	10.72240	93	9.93346	14	10.78101	102	50	
.92478	15	.72333	93	.93360	14	.78203	102	51	
.92493	15	.72427	93	.93375	14	.78306	103	52	
.92508	14	.72520	93	.93389	14	.78409	103	53	
.92523	15	.72614	93	.93404	15	.78513	103	54	
9.92538	15	10.72707	93	9.93419	14	10.78616	103	55	
.92552	14	.72801	94	.93433	14	.78720	104	56	
.92567	15	.72895	94	.93448	14	.78823	103	57	
.92582	15	.72990	94	.93462	14	.78927	104	58	
.92597	14	.73084	94	.93477	14	.79031	104	59	
9.92612	15	10.73178	94	9.93491	14	10.79136	104	60	
Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.

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90
9.0
10.5
12.0
13.5
15.0
30.0
45.0
60.0
75.0

80
8.0
9.5
10.5
12.0
13.5
25.0
40.0
55.0
66.6

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10
20
30
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9
0.9
1.0
1.2
1.3
1.5
3.0
4.5
6.0
7.5

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4.1

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2.0
2.3
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5.1
7.7
10.3
12.9

15
1.5
1.7
1.9
2.2
2.5
5.0
7.5
10.0
12.5

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20
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14
1.4
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12.1

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

82°

83°

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

84°

85°

										P. P.		
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D				
0	9.95205	14	10.93281	134	9.96039	14	11.02010	158	0			
1	.95219	14	.93416	135	.96053	13	.02168	159	1			
2	.95233	14	.93551	135	.96067	14	.02327	159	2			
3	.95247	14	.93686	135	.96081	14	.02487	159	3			
4	.95261	14	.93821	135	.96095	14	.02646	159	4			
5	9.95275	14	10.93957	135	9.96108	13	11.02807	160	5			
6	.95289	14	.94093	136	.96122	14	.02968	161	6			
7	.95303	14	.94229	136	.96136	13	.03129	161	7			
8	.95317	14	.94366	137	.96150	14	.03291	161	8			
9	.95331	14	.94503	137	.96163	13	.03453	162	9			
10	9.95345	14	10.94641	137	9.96177	14	11.03616	163	10			
11	.95359	14	.94778	137	.96191	13	.03780	163	11			
12	.95373	13	.94917	138	.96205	14	.03944	164	12			
13	.95387	14	.95055	138	.96218	13	.04108	164	13			
14	.95401	14	.95194	139	.96232	14	.04273	165	14			
15	9.95415	14	10.95333	139	9.96246	13	11.04438	165	15			
16	.95429	14	.95473	139	.96259	13	.04604	166	16			
17	.95443	14	.95613	140	.96273	14	.04771	167	17			
18	.95457	14	.95753	140	.96287	13	.04938	167	18			
19	.95471	14	.95894	140	.96301	14	.05106	167	19			
20	9.95485	14	10.96035	141	9.96314	13	11.05274	168	20			
21	.95499	14	.96176	141	.96328	14	.05443	169	21			
22	.95513	14	.96318	142	.96342	13	.05612	169	22			
23	.95527	14	.96461	142	.96355	13	.05782	170	23			
24	.95540	13	.96603	142	.96369	14	.05952	171	24			
25	9.95554	14	10.96746	143	9.96383	13	11.06123	171	25			
26	.95568	14	.96889	143	.96397	14	.06295	171	26			
27	.95582	14	.97033	144	.96410	13	.06467	172	27			
28	.95596	14	.97177	144	.96424	13	.06640	173	28			
29	.95610	14	.97322	144	.96438	14	.06813	173	29			
30	9.95624	14	10.97467	145	9.96451	13	11.06987	174	30			
31	.95638	13	.97612	145	.96465	13	.07161	174	31			
32	.95652	14	.97758	145	.96479	14	.07336	175	32			
33	.95666	14	.97904	146	.96492	13	.07512	176	33			
34	.95680	14	.98050	146	.96506	13	.07688	176	34			
35	9.95693	13	10.98197	147	9.96519	13	11.07865	177	35			
36	.95707	14	.98345	147	.96533	14	.08043	177	36			
37	.95721	14	.98492	147	.96547	13	.08221	178	37			
38	.95735	14	.98640	148	.96560	13	.08400	179	38			
39	.95749	14	.98789	149	.96574	14	.08579	179	39			
40	9.95763	13	10.98938	149	9.96588	13	11.08759	180	40			
41	.95777	14	.99087	149	.96601	13	.08940	180	41			
42	.95791	14	.99237	150	.96615	13	.09121	181	42			
43	.95804	13	.99387	150	.96629	14	.09303	182	43			
44	.95818	14	.99538	151	.96642	13	.09486	182	44			
45	9.95832	14	10.99689	151	9.96656	13	11.09669	183	45			
46	.95846	14	.99841	151	.96669	13	.09853	184	46			
47	.95860	13	10.99993	152	.96683	13	.10038	185	47			
48	.95874	14	11.00145	152	.96697	14	.10223	185	48			
49	.95888	14	.00298	153	.96710	13	.10409	186	49			
50	9.95901	13	11.00451	153	9.96724	13	11.10595	186	50			
51	.95915	14	.00605	154	.96737	13	.10783	187	51			
52	.95929	13	.00759	154	.96751	13	.10971	188	52			
53	.95943	14	.00914	155	.96764	13	.11160	189	53			
54	.95957	14	.01069	155	.96778	14	.11349	189	54			
55	9.95970	13	11.01225	155	9.96792	13	11.11539	190	55			
56	.95984	14	.01381	156	.96805	13	.11730	191	56			
57	.95998	14	.01537	156	.96819	13	.11922	191	57			
58	.96012	13	.01694	157	.96832	13	.12114	192	58			
59	.96026	14	.01852	157	.96846	13	.12307	193	59			
60	9.96039	13	11.02010	158	9.96859	13	11.12501	193	60			
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.		

190

180

6 19.0 18.0

7 22.1 21.0

8 25.3 24.0

9 28.5 27.0

10 31.6 30.0

20 63.3 60.0

30 95.0 90.0

40 126.6 120.0

50 158.3 150.0

170

160

6 17.0 16.0

7 19.8 18.6

8 22.6 21.3

9 25.5 24.0

10 28.3 26.6

20 56.0 53.3

30 85.0 80.0

40 113.3 106.6

50 141.6 133.3

150

140

6 15.0 14.0

7 17.5 16.3

8 20.0 18.6

9 22.5 21.0

10 25.0 23.3

20 50.0 46.6

30 75.0 70.0

40 100.0 93.3

50 125.0 116.6

130

9

8

6 13.0 0.9 0.8

7 15.1 1.0 0.6

8 17.3 1.2 1.0

9 19.5 1.3 1.2

10 21.6 1.5 1.3

20 43.3 3.0 2.6

30 65.0 4.5 4.0

40 86.6 6.0 5.3

50 108.3 7.5 6.6

7

6

5

6 0.7 0.6 0.5

7 0.8 0.7 0.6

8 0.9 0.8 0.6

9 1.0 0.9 0.7

10 1.1 1.0 0.8

20 2.3 2.0 1.6

30 3.5 3.0 2.5

40 4.6 4.0 3.3

50 5.8 5.0 4.1

14

14

13

6 1.4 1.4 1.3

7 1.7 1.6 1.0

8 1.9 1.8 1.8

9 2.2 2.1 2.0

10 2.4 2.3 2.2

20 4.8 4.6 4.5

30 7.2 7.0 6.7

40 9.6 9.3 9.0

50 12.1 11.6 11.2

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

86°

87°

TABLE VIII.—LOGARITHMIC VERSED SINES AND EXTERNAL SECANTS.

88°

89°

	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.
0	9.98457	13	11.44175	376	9.99235	12	11.75050	742	0	
1	.98470	13	.44551	379	.99248	13	.75792	755	1	
2	.98483	13	.44931	382	.99261	13	.76547	768	2	
3	.98496	13	.45313	386	.99274	13	.77316	781	3	
4	.98509	13	.45699	389	.99287	13	.78097	795	4	
5	9.98522	13		392	9.99299	12	11.78892	809	5	
6	.98535	13		395	.99312	13	.79702	825	6	
7	.98548	13		399	.99325	13	.80527	840	7	
8	.98562	13		402	.99338	12	.81367	856	8	
9	.98575	13		406	.99351	13	.82223	872	9	
10	9.98588	13		409	9.99363	12	11.83095	896	10	
11	.98601	13	.48493	413	.99376	13	.83986	908	11	
12	.98614	13	.48906	417	.99389	13	.84894	927	12	
13	.98627	13	.49323	420	.99402	12	.85821	947	13	
14	.98640	13	.49743	425	.99415	13	.86768	967	14	
15	9.98653	13	11.50168	428	9.99428	12	11.87735	989	15	
16	.98666	13	.50597	432	.99440	13	.88724	1009	16	
17	.98679	13	.51029	436	.99453	12	.89735	1034	17	
18	.98692	13	.51466	440	.99466	13	.90769	1059	18	
19	.98705	13	.51906	445	.99479	12	.91829	1085	19	
20	9.98718	13	11.52351	449	9.99491	13	11.92914	1112	20	
21	.98731	13	.52801	454	.99504	13	.94026	1140	21	
22	.98744	13	.53255	458	.99517	12	.95167	1171	22	
23	.98757	13	.53713	463	.99530	13	.96338	1203	23	
24	.98770	13	.54176	467	.99543	12	.97541	1236	24	
25	9.98783	13	11.54643	472	9.99555	13	11.98777	1271	25	
26	.98796	13	.55116	477	.99568	12	12.00048	1309	26	
27	.98809	13	.55593	482	.99581	13	.01358	1349	27	
28	.98822	13	.56076	487	.99594	12	.02707	1391	28	
29	.98835	13	.56563	492	.99606	13	.04098	1436	29	
30	9.98848	13	11.57056	498	9.99619	12	12.05535	1485	30	
31	.98861	13	.57554	504	.99632	13	.07020	1537	31	
32	.98874	13	.58058	509	.99645	12	.08557	1592	32	
33	.98887	13	.58567	515	.99657	13	.10149	1652	33	
34	.98900	13	.59082	520	.99670	12	.11801	1716	34	
35	9.98913	12	11.59602	527	9.99683	13	12.13517	1785	35	
36	.98925	13	.60129	533	.99695	12	.15302	1861	36	
37	.98938	13	.60662	539	.99708	13	.17163	1943	37	
38	.98951	13	.61202	545	.99721	12	.19106	2033	38	
39	.98964	13	.61747	552	.99734	13	.21139	2131	39	
40	9.98977	13	11.62300	559	9.99746	12	12.23271	2240	40	
41	.98990	13	.62859	566	.99759	13	.25511	2361	41	
42	.99003	13	.63425	573	.99772	12	.27872	2495	42	
43	.99016	12	.63998	581	.99784	13	.30367	2645	43	
44	.99029	13	.64579	588	.99797	12	.33013	2815	44	
45	9.99042	13	11.65167	595	9.99810	13	12.35828	3009	45	
46	.99055	13	.65762	604	.99823	12	.38837	3231	46	
47	.99068	13	.66366	611	.99835	13	.42068	3486	47	
48	.99081	12	.66978	620	.99848	12	.45557	3791	48	
49	.99093	13	.67598	628	.99861	13	.49349	4152	49	
50	9.99106	13	11.68227	638	9.99873	12	12.53501	4588	50	
51	.99119	13	.68865	646	.99886	13	.58089	5127	51	
52	.99132	13	.69511	656	.99899	12	.63217	5812	52	
53	.99145	12	.70168	666	.99911	13	.69029	6707	53	
54	.99158	13	.70834	675	.99924	12	.75736	7931	54	
55	9.99171	13	11.71509	686	9.99937	13	12.83667	9704	55	
56	.99184	13	.72196	696	.99949	12	.93371	12506	56	
57	.99197	12	.72892	707	.99962	13	13.05877	17621	57	
58	.99209	13	.73600	719	.99974	12	.23499	30116	58	
59	.99222	13	.74319	730	.99987	13	.53615		59	
60	9.99235		11.75050		10.00000		Infinity		60	
	Log. Vers.	D	Log. Exsec.	D	Log. Vers.	D	Log. Exsec.	D		P. P.

6	1.3	1.3
7	1.6	1.3
8	1.8	1.3
9	2.0	1.3
10	2.2	1.3
20	4.5	4.5
30	6.7	6.6
40	9.0	8.6
50	11.2	10.8

6	1.3	1.3
7	1.6	1.3
8	1.8	1.3
9	2.0	1.3
10	2.2	1.3
20	4.5	4.5
30	6.7	6.6
40	9.0	8.6
50	11.2	10.8

TABLE IX.—NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.
0°-10°

°	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	P. P.
0 0	0.0000		0.0000		∞		1.0000		0 90
10	0.0029	29		29	343.773		1.0000	0	50
20	0.0058	29		29	171.885		1.0000	0	40
30	0.0087	29		29	114.588		0.9999	0	30
40	0.0116	29		29	85.9398		0.9999	0	20
50	0.0145	29		29	68.7501		0.9999	0	10
1 0	0.0174	29		29	57.2899		0.9998	0	0 80
10	0.0203	29		29	49.1039	8.1865	0.9998	0	50
20	0.0232	29	0.0233	29	42.9641	6.1398	0.9997	0	40
30	0.0262	29	0.0262	29	38.1884	4.7756	0.9996	1	30
40	0.0291	29	0.0291	29	34.3677	3.8217	0.9996	1	20
50	0.0320	29	0.0320	29	31.2416	3.1261	0.9995	1	10
2 0	0.0349	29	0.0349	29	28.6362	2.6053	0.9994	1	0 88
10	0.0378	29	0.0378	29	26.4316	2.2046	0.9993	1	50
20	0.0407	29	0.0407	29	24.5417	1.8898	0.9991	1	40
30	0.0436	29	0.0436	29	22.9037	1.6380	0.9990	1	30
40	0.0465	29	0.0466	29	21.4704	1.4333	0.9989	1	20
50	0.0494	29	0.0495	29	20.2053	1.2648	0.9988	1	10
3 0	0.0523	29	0.0524	29	19.0811	1.1244	0.9986	1	0 87
10	0.0552	29	0.0553	29	18.0750	1.0061	0.9984	1	50
20	0.0581	29	0.0582	29	17.1693	.9056	0.9983	1	40
30	0.0610	29	0.0611	29	16.3498	.8195	0.9981	1	30
40	0.0639	29	0.0641	29	15.6048	.7450	0.9979	1	20
50	0.0668	29	0.0670	29	14.9244	.6804	0.9977	1	10
4 0	0.0697	29	0.0699	29	14.3006	.6237	0.9975	1	0 86
10	0.0726	29	0.0728	29	13.7267	.5739	0.9973	1	50
20	0.0755	29	0.0758	29	13.1969	.5298	0.9971	1	40
30	0.0784	29	0.0787	29	12.7062	.4907	0.9969	1	30
40	0.0813	29	0.0816	29	12.2505	.4557	0.9967	1	20
50	0.0842	29	0.0845	29	11.8261	.4243	0.9964	1	10
5 0	0.0871	29	0.0875	29	11.4306	.3961	0.9962	1	0 85
10	0.0900	29	0.0904	29	11.0594	.3706	0.9959	1	50
20	0.0929	29	0.0933	29	10.7119	.3475	0.9956	1	40
30	0.0958	29	0.0963	29	10.3854	.3265	0.9954	1	30
40	0.0987	29	0.0992	29	10.0786	.3073	0.9951	1	20
50	0.1016	29	0.1021	29	9.7881	.2899	0.9948	1	10
6 0	0.1045	29	0.1051	29	9.5143	.2738	0.9945	1	0 84
10	0.1074	29	0.1080	29	9.2553	.2590	0.9942	1	50
20	0.1103	29	0.1110	29	9.0098	.2454	0.9939	1	40
30	0.1132	29	0.1139	29	8.7769	.2329	0.9935	1	30
40	0.1161	29	0.1169	29	8.5555	.2213	0.9932	1	20
50	0.1190	29	0.1198	29	8.3449	.2106	0.9929	1	10
7 0	0.1218	29	0.1228	29	8.1443	.2006	0.9925	1	0 83
10	0.1247	29	0.1257	29	7.9530	.1913	0.9922	1	50
20	0.1276	29	0.1287	29	7.7703	.1826	0.9918	1	40
30	0.1305	29	0.1316	29	7.5957	.1746	0.9914	1	30
40	0.1334	29	0.1346	29	7.4287	.1676	0.9910	1	20
50	0.1363	29	0.1376	29	7.2687	.1599	0.9906	1	10
8 0	0.1391	29	0.1405	29	7.1153	.1534	0.9902	1	0 82
10	0.1420	29	0.1435	29	6.9682	.1471	0.9898	1	50
20	0.1449	29	0.1465	29	6.8269	.1413	0.9894	1	40
30	0.1478	29	0.1494	29	6.6911	.1358	0.9890	1	30
40	0.1507	29	0.1524	29	6.5605	.1306	0.9886	1	20
50	0.1535	29	0.1554	29	6.4348	.1257	0.9881	1	10
9 0	0.1564	29	0.1584	29	6.3137	.1211	0.9877	1	0 81
10	0.1593	29	0.1613	29	6.1970	.1167	0.9872	1	50
20	0.1622	29	0.1643	29	6.0844	.1126	0.9867	1	40
30	0.1650	29	0.1673	29	5.9757	.1087	0.9863	1	30
40	0.1679	29	0.1703	29	5.8708	.1049	0.9858	1	20
50	0.1708	29	0.1733	29	5.7693	.1014	0.9853	1	10
10 0	0.1736	29	0.1763	29	5.6713	.980	0.9848	1	0 80
	Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	P. P.

	30	25	20
1	3.0	2.9	2.8
2	5.0	4.9	4.8
3	7.0	6.9	6.8
4	9.0	8.9	8.8
5	11.0	10.9	10.8
6	13.0	12.9	12.8
7	15.0	14.9	14.8
8	17.0	16.9	16.8
9	19.0	18.9	18.8
10	21.0	20.9	20.8
11	23.0	22.9	22.8
12	25.0	24.9	24.8
13	27.0	26.9	26.8
14	29.0	28.9	28.8
15	31.0	30.9	30.8
16	33.0	32.9	32.8
17	35.0	34.9	34.8
18	37.0	36.9	36.8
19	39.0	38.9	38.8
20	41.0	40.9	40.8
21	43.0	42.9	42.8
22	45.0	44.9	44.8
23	47.0	46.9	46.8
24	49.0	48.9	48.8
25	51.0	50.9	50.8
26	53.0	52.9	52.8
27	55.0	54.9	54.8
28	57.0	56.9	56.8
29	59.0	58.9	58.8
30	61.0	60.9	60.8

TABLE IX.—NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.
10°-20°

°	'	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.		P. P.
10	0	0.1736	28	0.1763	30	5.6713	949	0.9848	5	0 80	
	10	0.1765	28	0.1793	30	5.5764	919	0.9843	5	50	
	20	0.1793	29	0.1823	30	5.4845	890	0.9838	5	40	
	30	0.1822	28	0.1853	30	5.3955	862	0.9832	5	30	
	40	0.1851	28	0.1883	30	5.3093	836	0.9827	5	20	
	50	0.1879	28	0.1913	30	5.2256	811	0.9822	5	10	
11	0	0.1908	28	0.1944	30	5.1445	787	0.9816	6	0 79	
	10	0.1936	28	0.1974	30	5.0658	764	0.9810	5	50	
	20	0.1965	28	0.2004	30	4.9894	742	0.9805	6	40	
	30	0.1993	28	0.2034	30	4.9151	721	0.9799	3	30	
	40	0.2022	28	0.2065	30	4.8430	701	0.9793	6	20	
	50	0.2050	28	0.2095	30	4.7728	682	0.9787	6	10	
12	0	0.2079	28	0.2125	30	4.7046	664	0.9781	6	0 78	
	10	0.2107	28	0.2156	30	4.6382	646	0.9775	6	50	
	20	0.2136	28	0.2186	30	4.5736	629	0.9769	6	40	
	30	0.2164	28	0.2217	30	4.5107	613	0.9763	6	30	
	40	0.2193	28	0.2247	30	4.4494	597	0.9756	6	20	
	50	0.2221	28	0.2278	30	4.3897	582	0.9750	6	10	
18	0	0.2249	28	0.2308	30	4.3315	568	0.9743	6	0 77	
	10	0.2278	28	0.2339	31	4.2747	553	0.9737	6	50	
	20	0.2306	28	0.2370	30	4.2193	540	0.9730	6	40	
	30	0.2334	28	0.2401	31	4.1653	527	0.9723	7	30	
	40	0.2362	28	0.2431	30	4.1125	515	0.9717	6	20	
	50	0.2391	28	0.2462	31	4.0610	502	0.9710	7	10	
14	0	0.2419	28	0.2493	31	4.0108	491	0.9703	7	0 76	
	10	0.2447	28	0.2524	30	3.9616	480	0.9696	7	50	
	20	0.2475	28	0.2555	31	3.9136	469	0.9688	7	40	
	30	0.2504	28	0.2586	31	3.8667	458	0.9681	7	30	
	40	0.2532	28	0.2617	31	3.8208	449	0.9674	7	20	
	50	0.2560	28	0.2648	31	3.7759	439	0.9666	7	10	
15	0	0.2588	28	0.2679	31	3.7328	429	0.9659	8	0 75	
	10	0.2616	28	0.2710	31	3.6891	420	0.9651	7	50	
	20	0.2644	28	0.2742	31	3.6470	411	0.9644	7	40	
	30	0.2672	28	0.2773	31	3.6059	403	0.9636	8	30	
	40	0.2700	28	0.2804	31	3.5655	394	0.9628	8	20	
	50	0.2728	28	0.2836	31	3.5261	387	0.9620	8	10	
16	0	0.2756	28	0.2867	31	3.4874	379	0.9612	8	0 74	
	10	0.2784	28	0.2899	31	3.4495	371	0.9604	8	50	
	20	0.2812	27	0.2930	31	3.4123	364	0.9596	8	40	
	30	0.2840	28	0.2962	32	3.3759	357	0.9588	8	30	
	40	0.2868	28	0.2994	31	3.3402	350	0.9580	8	20	
	50	0.2896	27	0.3025	32	3.3052	343	0.9571	8	10	
17	0	0.2923	28	0.3057	31	3.2708	337	0.9563	8	0 73	
	10	0.2951	28	0.3089	32	3.2371	331	0.9554	8	50	
	20	0.2979	27	0.3121	32	3.2040	324	0.9546	9	40	
	30	0.3007	28	0.3153	32	3.1716	319	0.9537	8	30	
	40	0.3035	27	0.3185	32	3.1397	313	0.9528	9	20	
	50	0.3062	27	0.3217	32	3.1084	307	0.9519	9	10	
18	0	0.3090	28	0.3249	32	3.0777	302	0.9510	9	0 72	
	10	0.3118	27	0.3281	32	3.0475	296	0.9501	9	50	
	20	0.3145	27	0.3313	32	3.0178	291	0.9492	9	40	
	30	0.3173	27	0.3346	32	2.9887	286	0.9483	9	30	
	40	0.3200	27	0.3378	32	2.9600	281	0.9474	9	20	
	50	0.3228	27	0.3411	32	2.9319	277	0.9464	9	10	
19	0	0.3255	27	0.3443	32	2.9042	272	0.9455	9	0 71	
	10	0.3283	27	0.3476	32	2.8770	267	0.9445	9	50	
	20	0.3310	27	0.3508	32	2.8502	263	0.9436	9	40	
	30	0.3338	27	0.3541	33	2.8239	259	0.9426	10	30	
	40	0.3365	27	0.3574	33	2.7980	254	0.9416	9	20	
	50	0.3393	27	0.3607	32	2.7725	250	0.9407	10	10	
20	0	0.3420		0.3639		2.7475		0.9397		0 70	
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	' °	P. P.

TABLE IX.—NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.
20°-30°

°	'	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	'	°	P. P.
20	0	0.3420		0.3639		2.7475		0.9397		0	70	
	10	0.3447	27	0.3672	33	2.7228	247	0.9387	10	50		
	20	0.3475	27	0.3705	33	2.6985	245	0.9377	10	40		
	30	0.3503	27	0.3739	33	2.6746	243	0.9366	10	30		
	40	0.3529	27	0.3772	33	2.6511	241	0.9356	10	20		
	50	0.3556	27	0.3805	33	2.6279	239	0.9346	10	10		5
21	0	0.3583	27	0.3838	33	2.6051	238	0.9336	10	0	69	6
	10	0.3611	27	0.3872	33	2.5826	235	0.9325	10	50		8
	20	0.3638	27	0.3905	33	2.5604	232	0.9315	10	40		4
	30	0.3665	27	0.3939	33	2.5386	230	0.9304	11	30		6
	40	0.3692	27	0.3972	34	2.5171	228	0.9293	11	20		2
	50	0.3719	27	0.4006	34	2.4959	226	0.9282	11	10		8
22	0	0.3746	27	0.4040	33	2.4751	225	0.9272	11	0	68	4
	10	0.3773	27	0.4074	34	2.4545	223	0.9261	11	50		
	20	0.3800	27	0.4108	34	2.4342	220	0.9250	11	40		
	30	0.3827	26	0.4142	34	2.4142	217	0.9239	11	30		33
	40	0.3853	27	0.4176	34	2.3945	215	0.9227	11	20		3.3
	50	0.3880	27	0.4210	34	2.3750	213	0.9216	11	10		6.6
23	0	0.3907	26	0.4244	34	2.3558	212	0.9205	11	0	67	9.9
	10	0.3934	27	0.4279	34	2.3369	209	0.9193	11	50		13.2
	20	0.3961	26	0.4313	34	2.3182	207	0.9182	11	40		16.5
	30	0.3989	26	0.4348	35	2.2998	204	0.9170	11	30		19.8
	40	0.4014	27	0.4383	34	2.2816	202	0.9159	12	20		23.1
	50	0.4041	26	0.4417	35	2.2637	200	0.9147	12	10		26.4
24	0	0.4067	26	0.4452	34	2.2460	198	0.9135	12	0	66	29.7
	10	0.4094	26	0.4487	35	2.2285	197	0.9123	12	50		
	20	0.4120	26	0.4522	35	2.2113	195	0.9111	12	40		
	30	0.4147	26	0.4557	35	2.1943	193	0.9099	12	30		
	40	0.4173	26	0.4592	35	2.1775	191	0.9087	12	20		
	50	0.4200	26	0.4627	35	2.1609	189	0.9075	12	10		
25	0	0.4226	26	0.4663	35	2.1445	188	0.9063	12	0	65	
	10	0.4252	26	0.4698	35	2.1283	186	0.9050	12	50		
	20	0.4279	26	0.4734	36	2.1123	185	0.9038	12	40		
	30	0.4305	26	0.4770	35	2.0965	183	0.9026	12	30		
	40	0.4331	26	0.4805	36	2.0809	181	0.9013	13	20		
	50	0.4357	26	0.4841	36	2.0655	180	0.9000	13	10		
26	0	0.4383	26	0.4877	36	2.0503	178	0.8988	13	0	64	
	10	0.4410	26	0.4913	36	2.0352	177	0.8975	13	50		
	20	0.4436	26	0.4949	36	2.0204	175	0.8962	13	40		
	30	0.4462	26	0.4986	36	2.0057	173	0.8949	13	30		
	40	0.4488	26	0.5022	36	1.9911	171	0.8936	13	20		
	50	0.4514	26	0.5058	36	1.9768	170	0.8923	13	10		
27	0	0.4540	26	0.5095	37	1.9626	168	0.8910	13	0	63	
	10	0.4566	25	0.5132	37	1.9486	167	0.8897	13	50		
	20	0.4591	26	0.5169	36	1.9347	165	0.8883	13	40		
	30	0.4617	26	0.5205	37	1.9210	163	0.8870	13	30		
	40	0.4643	25	0.5242	37	1.9074	161	0.8856	13	20		
	50	0.4669	25	0.5280	37	1.8940	160	0.8843	13	10		
28	0	0.4694	26	0.5317	37	1.8807	158	0.8829	13	0	62	
	10	0.4720	25	0.5354	37	1.8676	157	0.8816	14	50		
	20	0.4746	25	0.5392	37	1.8546	155	0.8802	14	40		
	30	0.4771	25	0.5429	38	1.8417	153	0.8788	14	30		
	40	0.4797	25	0.5467	37	1.8290	151	0.8774	14	20		
	50	0.4822	25	0.5505	38	1.8165	150	0.8760	14	10		
29	0	0.4848	25	0.5543	38	1.8040	148	0.8746	14	0	61	
	10	0.4873	25	0.5581	38	1.7917	147	0.8732	14	50		
	20	0.4899	25	0.5619	38	1.7795	145	0.8718	14	40		
	30	0.4924	25	0.5657	38	1.7675	143	0.8703	14	30		
	40	0.4949	25	0.5696	39	1.7555	141	0.8689	14	20		
	50	0.4975	25	0.5735	38	1.7437	140	0.8675	14	10		
30	0	0.5000	25	0.5773	38	1.7320	138	0.8660	14	0	60	
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	'	°	P. P.

TABLE IX.—NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.

30°-40°

°	'	Sin.	d.	Tan.	d.	Cot.	d.	Sec.	d.	P. P.
80	0	0.5000		0.5773		1.7320		0.8660		0 60
	10	0.5025	25	0.5812	39	1.7204	116	0.8645	13	50
	20	0.5050	25	0.5851	39	1.7090	114	0.8631	14	40
	30	0.5075	25	0.5890	39	1.6976	113	0.8616	14	30
	40	0.5100	25	0.5929	39	1.6864	112	0.8601	15	20
	50	0.5125	25	0.5969	39	1.6753	111	0.8586	15	10
81	0	0.5150	25	0.6008	39	1.6643	110	0.8571	15	0 59
	10	0.5175	25	0.6048	40	1.6533	109	0.8556	15	50
	20	0.5200	25	0.6088	40	1.6425	108	0.8541	15	40
	30	0.5225	25	0.6128	40	1.6318	107	0.8526	15	30
	40	0.5250	25	0.6168	40	1.6212	106	0.8511	15	20
	50	0.5274	24	0.6208	40	1.6107	105	0.8496	15	10
82	0	0.5299	24	0.6248	40	1.6003	104	0.8480	15	0 58
	10	0.5324	25	0.6289	40	1.5900	103	0.8465	15	50
	20	0.5348	24	0.6330	41	1.5798	102	0.8449	15	40
	30	0.5373	24	0.6370	40	1.5697	101	0.8434	15	30
	40	0.5397	24	0.6411	41	1.5596	100	0.8418	16	20
	50	0.5422	24	0.6453	42	1.5497	99	0.8402	15	10
83	0	0.5446	24	0.6494	41	1.5398	98	0.8386	16	0 57
	10	0.5471	24	0.6535	42	1.5301	97	0.8371	15	50
	20	0.5495	24	0.6577	42	1.5204	96	0.8355	16	40
	30	0.5519	24	0.6619	42	1.5108	95	0.8339	16	30
	40	0.5543	24	0.6661	42	1.5013	94	0.8323	16	20
	50	0.5568	24	0.6703	42	1.4919	93	0.8306	16	10
84	0	0.5592	24	0.6745	42	1.4825	92	0.8290	16	0 56
	10	0.5616	24	0.6787	42	1.4733	91	0.8274	16	50
	20	0.5640	24	0.6830	42	1.4641	90	0.8257	16	40
	30	0.5664	24	0.6873	42	1.4550	89	0.8241	16	30
	40	0.5688	24	0.6915	42	1.4460	88	0.8225	16	20
	50	0.5712	24	0.6959	42	1.4370	87	0.8208	17	10
85	0	0.5736	24	0.7002	42	1.4281	86	0.8191	16	0 55
	10	0.5759	23	0.7045	43	1.4193	85	0.8175	16	50
	20	0.5783	23	0.7089	43	1.4106	84	0.8158	17	40
	30	0.5807	23	0.7133	44	1.4019	83	0.8141	17	30
	40	0.5830	23	0.7177	44	1.3933	82	0.8124	17	20
	50	0.5854	24	0.7221	44	1.3848	81	0.8107	17	10
86	0	0.5878	23	0.7265	44	1.3764	80	0.8090	17	0 54
	10	0.5901	23	0.7310	44	1.3680	79	0.8073	17	50
	20	0.5925	23	0.7354	44	1.3597	78	0.8056	17	40
	30	0.5948	23	0.7399	45	1.3514	77	0.8038	17	30
	40	0.5971	23	0.7444	45	1.3432	76	0.8021	17	20
	50	0.5995	23	0.7490	45	1.3351	75	0.8004	17	10
87	0	0.6018	23	0.7535	45	1.3270	74	0.7986	17	0 53
	10	0.6041	23	0.7581	45	1.3196	73	0.7969	18	50
	20	0.6064	23	0.7627	46	1.3111	72	0.7951	17	40
	30	0.6087	23	0.7673	46	1.3032	71	0.7933	17	30
	40	0.6110	23	0.7719	46	1.2954	70	0.7916	17	20
	50	0.6133	23	0.7766	46	1.2876	69	0.7898	18	10
88	0	0.6156	23	0.7813	47	1.2799	68	0.7880	18	0 52
	10	0.6179	23	0.7860	47	1.2723	67	0.7862	18	50
	20	0.6202	23	0.7907	47	1.2647	66	0.7844	18	40
	30	0.6225	23	0.7954	47	1.2571	65	0.7826	18	30
	40	0.6248	23	0.8002	47	1.2497	64	0.7808	18	20
	50	0.6276	23	0.8050	48	1.2422	63	0.7789	18	10
89	0	0.6293	22	0.8098	48	1.2349	62	0.7771	18	0 51
	10	0.6316	22	0.8146	48	1.2276	61	0.7753	18	50
	20	0.6338	22	0.8194	48	1.2203	60	0.7734	18	40
	30	0.6361	22	0.8243	49	1.2131	59	0.7716	18	30
	40	0.6383	22	0.8292	49	1.2059	58	0.7697	18	20
	50	0.6405	22	0.8341	49	1.1988	57	0.7679	18	10
90	0	0.6428	22	0.8391	49	1.1917	56	0.7660	18	0 50
		Con.	d.	Cot.	d.	Tan.	d.	Sin.	d.	P. P.

50°-60°

TABLE IX.—NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.
40°-45°

°	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	P. P.
40 0	0.6428	22	0.8391	49	1.1917	70	0.7668	19	0 50
10	0.6450	22	0.8446	50	1.1847	70	0.7641	18	50
20	0.6472	22	0.8496	50	1.1777	69	0.7623	19	40
30	0.6494	22	0.8541	50	1.1708	68	0.7604	19	30
40	0.6516	22	0.8591	51	1.1640	68	0.7585	19	20
50	0.6538	22	0.8642	51	1.1571	68	0.7566	19	10
41 0	0.6568	22	0.8693	51	1.1503	67	0.7547	19	0 49
10	0.6582	22	0.8744	51	1.1436	67	0.7528	19	50
20	0.6604	21	0.8795	52	1.1369	66	0.7509	19	40
30	0.6626	22	0.8847	51	1.1303	66	0.7489	19	30
40	0.6648	21	0.8899	52	1.1237	65	0.7470	19	20
50	0.6669	22	0.8951	52	1.1171	65	0.7451	19	10
42 0	0.6691	21	0.9004	53	1.1106	64	0.7431	19	0 48
10	0.6713	21	0.9057	53	1.1041	64	0.7412	19	50
20	0.6734	21	0.9110	53	1.0977	64	0.7392	19	40
30	0.6756	21	0.9163	53	1.0913	63	0.7373	20	30
40	0.6777	21	0.9217	54	1.0849	63	0.7353	19	20
50	0.6798	21	0.9271	54	1.0786	63	0.7333	20	10
43 0	0.6820	21	0.9325	54	1.0723	62	0.7313	20	0 47
10	0.6841	21	0.9379	55	1.0661	62	0.7293	20	50
20	0.6862	21	0.9434	55	1.0599	61	0.7273	20	40
30	0.6883	21	0.9489	55	1.0538	61	0.7253	20	30
40	0.6904	21	0.9545	56	1.0476	60	0.7233	20	20
50	0.6925	21	0.9601	56	1.0416	60	0.7213	20	10
44 0	0.6946	21	0.9657	56	1.0355	60	0.7193	20	0 46
10	0.6967	21	0.9713	56	1.0295	59	0.7173	20	50
20	0.6988	21	0.9770	56	1.0235	59	0.7153	20	40
30	0.7009	20	0.9827	57	1.0176	59	0.7132	20	30
40	0.7030	21	0.9884	57	1.0117	59	0.7112	20	20
50	0.7058	20	0.9942	57	1.0058	58	0.7091	20	10
45 0	0.7071	20	1.0000	58	1.0000	58	0.7071	20	0 45
	Sec.	d.	Cot.	d.	Tan.	d.	Sin.	d.	°

65	64	63	62	61	60	59	58	57	56	55	54	53	52	51
1 6.8	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.7	5.6	5.5	5.4
2 13.1	12.9	12.8	12.6	12.5	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.5
3 19.6	19.3	19.2	19.0	18.9	18.8	18.7	18.6	18.5	18.4	18.3	18.2	18.1	18.0	17.9
4 26.2	25.8	25.6	25.5	25.4	25.3	25.2	25.1	25.0	24.9	24.8	24.7	24.6	24.5	24.4
5 32.7	32.3	32.0	31.9	31.8	31.7	31.6	31.5	31.4	31.3	31.2	31.1	31.0	30.9	30.8
6 39.3	38.7	38.4	38.3	38.2	38.1	38.0	37.9	37.8	37.7	37.6	37.5	37.4	37.3	37.2
7 45.8	45.2	44.8	44.7	44.6	44.5	44.4	44.3	44.2	44.1	44.0	43.9	43.8	43.7	43.6
8 52.4	51.6	51.2	51.0	50.9	50.8	50.7	50.6	50.5	50.4	50.3	50.2	50.1	50.0	49.9
9 58.9	58.0	57.6	57.5	57.4	57.3	57.2	57.1	57.0	56.9	56.8	56.7	56.6	56.5	56.4

Table for passing from Sexagesimal to Circular Measure.

°	Circular Meas.	'	Circular Meas.	"	Circular Meas.
100	1.74 532 9	10	0.00 290 9	10	0.00 004 8
200	3.49 065 8	20	0.00 581 8	20	0.00 009 7
300	5.23 598 8	30	0.00 872 6	30	0.00 014 5
		40	0.01 163 5	40	0.00 019 4
40	0.69 813 1				
50	0.87 266 4	50	0.01 454 4	50	0.00 024 3
60	1.04 719 7				
		6	0.00 174 5	6	0.00 002 9
70	1.22 173 0	7	0.00 203 6	7	0.00 003 4
80	1.39 626 3	8	0.00 232 7	8	0.00 003 9
90	1.57 079 6	9	0.00 261 8	9	0.00 004 3

TABLE X.—NATURAL VERSED SINES AND EXTERNAL SECANTS.

0°-10°

10°-20°

°	'	Vers.	d.	Exsec.	d.	°	'	Vers.	d.	Exsec.	d.	P. P.									
0	0	.00000	0	.00000	0	10	0	.01519	51	.01542	52										
10		.00006	1	.00006	1	10	10	.01570	52	.01595	53										
20		.00011	2	.00011	2	20		.01622	52	.01648	54										
30		.00014	3	.00014	3	30		.01674	53	.01703	55										
40		.00017	3	.00017	3	40		.01728	53	.01758	56										
50		.00018	3	.00018	3	50		.01782	54	.01814	57										
1	0	.00015	4	.00015	4	11	0	.01837	55	.01871	58										
10		.00026	5	.00026	5	10		.01893	55	.01926	59										
20		.00027	6	.00027	6	20		.01950	57	.01988	60										
30		.00034	7	.00034	7	30		.02007	57	.02048	61										
40		.00042	8	.00042	8	40		.02066	58	.02109	62										
50		.00051	8	.00051	10	50		.02125	59	.02171	62										
2	0	.00061	10	.00061	10	12	0	.02185	60	.02234	63										
10		.00071	11	.00071	11	10		.02246	61	.02297	63										
20		.00083	12	.00083	12	20		.02308	62	.02362	65										
30		.00095	13	.00095	13	30		.02370	63	.02428	66										
40		.00108	13	.00108	14	40		.02434	64	.02494	67										
50		.00122	15	.00122	14	50		.02498	65	.02562	68										
3	0	.00137	15	.00137	16	18	0	.02563	66	.02636	69										
10		.00152	16	.00153	16	10		.02629	66	.02700	70										
20		.00169	17	.00169	17	20		.02695	67	.02770	71										
30		.00186	18	.00187	18	30		.02763	68	.02841	72										
40		.00204	19	.00205	19	40		.02831	69	.02914	73										
50		.00223	20	.00224	20	50		.02900	70	.02987	74										
4	0	.00243	21	.00244	21	14	0	.02976	70	.03061	75										
10		.00264	21	.00265	21	10		.03041	72	.03136	75										
20		.00286	22	.00286	22	20		.03113	72	.03213	76										
30		.00308	23	.00309	23	30		.03185	72	.03290	77										
40		.00331	24	.00332	24	40		.03258	72	.03368	78										
50		.00355	25	.00357	25	50		.03332	74	.03447	79										
5	0	.00386	25	.00382	26	15	0	.03407	75	.03527	80										
10		.00406	26	.00408	26	10		.03483	75	.03609	81										
20		.00433	26	.00435	27	20		.03559	76	.03691	82										
30		.00466	27	.00462	27	30		.03637	77	.03774	83										
40		.00488	28	.00491	28	40		.03715	78	.03858	84										
50		.00518	29	.00526	29	50		.03794	79	.03943	85										
6	0	.00548	30	.00551	30	16	0	.03874	80	.04030	86										
10		.00578	30	.00582	31	10		.03954	85	.04117	87										
20		.00610	32	.00614	32	20		.04036	81	.04205	88										
30		.00643	32	.00647	33	30		.04118	82	.04295	89										
40		.00676	33	.00681	34	40		.04201	83	.04385	90										
50		.00710	33	.00715	34	50		.04285	84	.04476	91										
7	0	.00745	35	.00751	35	17	0	.04366	84	.04569	92										
10		.00781	36	.00789	36	10		.04455	85	.04662	93										
20		.00818	36	.00824	37	20		.04541	86	.04757	95										
30		.00855	37	.00863	38	30		.04628	87	.04853	95										
40		.00894	38	.00902	39	40		.04716	87	.04949	96										
50		.00933	39	.00942	40	50		.04805	89	.05047	98										
8	0	.00973	40	.00983	41	18	0	.04894	89	.05146	98										
10		.01014	41	.01024	41	10		.04984	90	.05246	100										
20		.01056	42	.01067	42	20		.05076	91	.05347	101										
30		.01098	42	.01110	43	30		.05167	91	.05449	102										
40		.01142	43	.01155	44	40		.05260	93	.05552	103										
50		.01186	44	.01200	45	50		.05354	93	.05656	104										
9	0	.01231	45	.01246	46	19	0	.05448	94	.05762	105										
10		.01277	46	.01293	47	10		.05543	95	.05868	106										
20		.01324	47	.01341	48	20		.05639	95	.05976	107										
30		.01371	47	.01396	49	30		.05736	97	.06085	109										
40		.01420	48	.01446	50	40		.05833	97	.06194	109										
50		.01469	49	.01491	51	50		.05931	98	.06305	111										
10	0	.01519	50	.01542	51	20	0	.06036	99	.06418	112										
°	'	Vers.	d.	Exsec.	d.	°	'	Vers.	d.	Exsec.	d.	P. P.									

110 100 90 80 70 60 50 40

1	11	10	9	8	7	6	5	4
2	22	20	18	16	14	12	10	8
3	33	30	27	24	21	18	15	12
4	44	40	36	32	28	24	20	16
5	55	50	45	40	35	30	25	20
6	66	60	54	48	42	36	30	24
7	77	70	63	56	49	42	35	28
8	88	80	72	64	56	48	40	32
9	99	90	81	72	63	54	45	36

TABLE X.—NATURAL VERSED SINES AND EXTERNAL SECANTS.

20°-30°

30°-40°

	Vers.	d.	Exsec.	d.		Vers.	d.	Exsec.	d.	P. P.
20 0	.0603	10	.0642	11	80 0	.1336	15	.1547	19	31 30 29 28
10	.0613	10	.0653	11	10	.1354	14	.1566	19	
20		10	.0664	11	20	.1369	14	.1586	20	
30		10	.0676	12	30	.1383	15	.1606	20	
40		10	.0688	11	40	.1398	15	.1626	20	
50		10	.0699	12	50	.1413	15	.1646	20	27 26 25 24
21 0		10	.0711	12	81 0	.1428	15	.1665	20	
10		10	.0723	12	10	.1443	15	.1687	20	
20	.0685	11	.0735	12	20	.1458	15	.1707	21	
30	.0696	10	.0748	12	30	.1473	15	.1728	21	
40	.0706	11	.0760	12	40	.1489	15	.1749	21	23 22 21 20
50	.0717	10	.0772	13	50	.1504	15	.1770	21	
22 0	.0728	11	.0785	12	82 0	.1519	15	.1792	21	
10	.0739	11	.0798	13	10	.1535	15	.1813	21	
20	.0750	11	.0811	13	20	.1550	15	.1835	22	
30	.0761	11	.0824	13	30	.1566	16	.1857	22	19 18 17 16
40	.0772	11	.0837	13	40	.1582	15	.1879	22	
50	.0783	11	.0850	13	50	.1597	16	.1901	22	
23 0	.0795	11	.0863	13	83 0	.1613	15	.1923	23	
10	.0806	11	.0877	13	10	.1629	16	.1946	22	
20	.0818	11	.0890	14	20	.1645	16	.1969	23	15 14 13 12
30	.0829	11	.0904	14	30	.1661	16	.1992	23	
40	.0841	12	.0918	14	40	.1677	16	.2015	23	
50	.0853	11	.0932	14	50	.1693	16	.2038	24	
24 0	.0864	12	.0946	14	84 0	.1709	16	.2062	24	
10	.0876	12	.0960	14	10	.1726	16	.2086	24	11 10 9
20	.0888	12	.0975	14	20	.1742	16	.2110	24	
30	.0900	12	.0989	14	30	.1758	16	.2134	24	
40	.0912	12	.1004	15	40	.1775	16	.2158	24	
50	.0924	12	.1019	15	50	.1792	17	.2183	24	
25 0	.0937	12	.1034	15	85 0	.1808	16	.2207	25	7 6 5 4 3 2 1
10	.0949	12	.1049	15	10	.1825	17	.2232	25	
20	.0961	12	.1064	15	20	.1842	17	.2258	25	
30	.0974	12	.1079	15	30	.1859	17	.2283	25	
40	.0986	12	.1094	16	40	.1876	17	.2309	25	
50	.0999	12	.1110	15	50	.1893	17	.2334	26	3 2 1 0 9 8 7 6 5 4 3 2 1
26 0	.1012	12	.1126	16	86 0	.1910	17	.2368	26	
10	.1025	12	.1142	16	10	.1927	17	.2387	26	
20	.1037	12	.1158	16	20	.1944	17	.2413	26	
30	.1050	12	.1174	16	30	.1961	17	.2440	27	
40	.1063	12	.1190	16	40	.1979	17	.2467	27	11 10 9 8 7 6 5 4 3 2 1
50	.1077	12	.1206	17	50	.1996	17	.2494	27	
27 0	.1090	12	.1223	16	87 0	.2013	17	.2521	27	
10	.1103	12	.1240	17	10	.2031	18	.2549	27	
20	.1116	12	.1257	17	20	.2049	17	.2576	28	
30	.1130	12	.1274	17	30	.2066	17	.2604	28	7 6 5 4 3 2 1
40	.1143	12	.1291	17	40	.2084	18	.2633	28	
50	.1157	12	.1308	17	50	.2102	18	.2661	28	
28 0	.1170	12	.1325	18	88 0	.2120	18	.2690	28	
10	.1184	13	.1343	17	10	.2138	18	.2719	29	
20	.1198	13	.1361	18	20	.2156	18	.2748	29	3 2 1 0 9 8 7 6 5 4 3 2 1
30	.1212	13	.1379	18	30	.2174	18	.2778	29	
40	.1225	13	.1397	18	40	.2192	18	.2807	30	
50	.1239	13	.1415	18	50	.2210	18	.2837	30	
29 0	.1254	13	.1433	18	89 0	.2228	18	.2867	30	
10	.1268	14	.1452	18	10	.2247	18	.2898	30	3 2 1 0 9 8 7 6 5 4 3 2 1
20	.1282	14	.1470	19	20	.2265	18	.2928	31	
30	.1296	14	.1489	19	30	.2284	18	.2959	31	
40	.1311	14	.1508	19	40	.2302	18	.2991	31	
50	.1325	14	.1527	19	50	.2321	18	.3022	31	
30 0	.1336	14	.1547		40 0	.2336	18	.3054		
	Vers.	d.	Exsec.	d.		Vers.	d.	Exsec.	d.	P. P.

TABLE X.—NATURAL VERSED SINES AND EXTERNAL SECANTS.

40°-50°

50°-60°

40 0				41 0				42 0				43 0				44 0				45 0				46 0				47 0				48 0				49 0				50 0			
Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.	Ver.	d.	Exsec.	d.								
.2339	19	.3054	32	.2453	19	.3250	34	.2568	19	.3456	35	.2686	20	.3673	37	.2806	20	.3901	39	.2929	20	.4142	41	.3053	21	.4395	43	.3180	21	.4663	45	.3308	22	.4945	48	.3439	22	.5242	51				
.2358	18	.3086	32	.2472	19	.3284	33	.2588	19	.3491	36	.2706	20	.3710	37	.2827	20	.3941	39	.2949	20	.4183	41	.3074	21	.4439	44	.3201	21	.4708	46	.3330	21	.4993	48	.3461	22	.5294	51				
.2377	19	.3118	32	.2491	19	.3317	34	.2607	19	.3527	36	.2726	20	.3748	38	.2847	20	.3980	40	.2970	21	.4225	42	.3095	21	.4483	44	.3222	21	.4755	47	.3352	22	.5042	49	.3483	22	.5345	52				
.2396	19	.3151	32	.2510	19	.3352	34	.2627	20	.3563	36	.2746	20	.3786	38	.2867	20	.4020	40	.2991	20	.4267	42	.3116	21	.4527	44	.3244	21	.4802	47	.3374	21	.5091	50	.3505	22	.5397	53				
.2415	19	.3183	33	.2529	19	.3386	34	.2647	19	.3599	37	.2766	20	.3824	39	.2888	20	.4060	40	.3011	21	.4309	43	.3137	21	.4572	45	.3265	21	.4849	47	.3395	22	.5141	50	.3527	22	.5450	53				
.2434	19	.3217	33	.2549	19	.3421	35	.2666	20	.3636	37	.2786	20	.3863	38	.2908	20	.4101	41	.3032	21	.4352	43	.3159	21	.4617	45	.3287	21	.4896	48	.3417	22	.5192	50	.3550	22	.5503	53				
.3572	22	.5557	53	.3707	22	.5890	57	.3843	23	.6242	61	.3982	23	.6618	64	.4122	23	.7013	68	.4264	24	.7434	73	.4408	24	.7883	77	.4553	24	.8361	82	.4701	24	.8871	88	.4849	25	.9416	94				
.3594	22	.5611	54	.3729	22	.5947	57	.3866	23	.6303	61	.4005	23	.6681	65	.4145	24	.7081	69	.4288	24	.7507	73	.4432	24	.7960	78	.4578	24	.8443	83	.4725	24	.8959	88	.4874	25	.9510	94				
.3617	22	.5666	54	.3752	22	.6005	58	.3889	23	.6365	61	.4028	23	.6746	65	.4169	24	.7156	70	.4312	24	.7581	74	.4456	24	.8039	79	.4578	24	.8443	83	.4750	25	.9048	86	.4899	25	.9606	95				
.3639	22	.5721	55	.3775	23	.6064	58	.3912	23	.6427	62	.4052	23	.6811	66	.4193	24	.7226	70	.4336	24	.7655	75	.4480	24	.8118	80	.4529	24	.8279	82	.4775	25	.9139	90	.4924	25	.9703	97				
.3661	22	.5777	55	.3797	22	.6123	59	.3935	23	.6489	62	.4075	23	.6878	66	.4216	24	.7291	71	.4360	24	.7730	75	.4505	24	.8198	81	.4529	24	.8279	82	.4800	24	.9230	92	.4949	25	.9801	99				
.3684	23	.5833	56	.3820	23	.6182	59	.3958	23	.6552	63	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3707	22	.5890	56	.3843	23	.6242	61	.3982	23	.6618	64	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3729	22	.5947	57	.3866	23	.6303	61	.4005	23	.6681	64	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3752	23	.6005	58	.3889	23	.6365	61	.4028	23	.6746	65	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3775	23	.6064	58	.3912	23	.6427	62	.4052	23	.6811	66	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3797	22	.6123	59	.3935	23	.6489	62	.4075	23	.6878	66	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3820	23	.6182	59	.3958	23	.6552	63	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3843	23	.6242	61	.3982	23	.6618	64	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3866	23	.6303	61	.4005	23	.6681	65	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3889	23	.6365	61	.4028	23	.6746	65	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3912	23	.6427	62	.4052	23	.6811	66	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3935	23	.6489	62	.4075	23	.6878	66	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3958	23	.6552	63	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.3982	23	.6618	64	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4005	23	.6681	65	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4028	23	.6746	65	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4052	23	.6811	66	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4075	23	.6878	66	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4122	23	.7013	68	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4145	24	.7081	68	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4169	24	.7156	69	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4193	24	.7226	70	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4216	24	.7291	71	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4240	24	.7362	72	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4264	24	.7434	73	.4098	23	.6945	67	.4098	23	.6945	67	.4098	23	.6945	67	.4240	24	.7362	72	.4384	24	.7806	77	.4529	24	.8279	82	.4529	24	.8279	82	.4824	25	.9322	93	.4975	25	.9900	100				
.4288	24	.7																																									

9 8 7 6 5 4

1	0.9	0.8	0.7	0.6	0.5	0.4
2	1.8	1.6	1.4	1.2	1.0	0.8
3	2.7	2.4	2.1	1.8	1.5	1.2
4	3.6	3.2	2.8	2.4	2.0	1.7
5	4.5	4.0	3.5	3.0	2.5	2.0
6	5.4	4.8	4.2	3.6	3.0	2.4
7	6.3	5.6	4.9	4.2	3.5	2.8
8	7.2	6.4	5.6	4.8	4.0	3.2
9	8.1	7.2	6.3	5.4	4.5	3.6

3 2 1 0 5 7

1	0.3	0.2	0.1	0.0	0.0	0.0
2	0.0	0.4	0.2	0.1	0.1	0.1
3	0.0	0.6	0.3	0.2	0.2	0.2
4	1.2	0.8	0.4	0.3	0.4	0.3
5	1.5	1.0	0.5	0.4	0.5	0.4
6	1.8	1.2	0.6	0.5	0.6	0.5
7	2.1	1.4	0.7	0.6	0.7	0.6
8	2.4	1.6	0.8	0.7	0.8	0.7
9	2.7	1.8	0.9	0.8	0.9	0.8

6 5 4 3 2 1

1	0.6	0.5	0.4	0.3	0.2	0.1
2	1.2	1.0	0.8	0.6	0.4	0.3
3	1.8	1.6	1.3	1.0	0.7	0.4
4	2.6	2.2	1.8	1.4	1.0	0.6
5	3.2	2.7	2.2	1.7	1.2	0.7
6	3.9	3.2	2.7	2.1	1.5	0.9
7	4.5	3.8	3.1	2.4	1.7	1.0
8	5.2	4.3	3.6	2.7	2.0	1.2
9	5.8	4.9	4.0	3.1	2.2	1.3

25 25 24 24 23 23

5	2.5	2.4	2.4	2.3	2.2	2.1
6	3.1	3.0	2.9	2.8	2.7	2.6
7	3.7	3.6	3.5	3.4	3.3	3.2
8	4.3	4.2	4.1	4.0	3.9	3.8
9	4.9	4.8	4.7	4.6	4.5	4.4
10	5.5	5.4	5.3	5.2	5.1	5.0
11	6.1	6.0	5.9	5.8	5.7	5.6
12	6.7	6.6	6.5	6.4	6.3	6.2
13	7.3	7.2	7.1	7.0	6.9	6.8
14	7.9	7.8	7.7	7.6	7.5	7.4
15	8.5	8.4	8.3	8.2	8.1	8.0
16	9.1	9.0	8.9	8.8	8.7	8.6
17	9.7	9.6	9.5	9.4	9.3	9.2
18	10.3	10.2	10.1	10.0	9.9	9.8
19	10.9	10.8	10.7	10.6	10.5	10.4
20	11.5	11.4	11.3	11.2	11.1	11.0

22 22 21 21 20 20

1	2.2	2.2	2.1	2.1	2.0	2.0
2	4.5	4.4	4.3	4.2	4.1	4.0
3	6.7	6.6	6.4	6.3	6.1	6.0
4	9.0	8.8	8.6	8.4	8.2	8.0
5	11.3	11.0	10.7	10.5	10.2	10.0
6	13.5	13.2	12.9	12.6	12.3	12.0
7	15.7	15.4	15.0	14.7	14.4	14.0
8	18.0	17.6	17.2	16.8	16.4	16.0
9	20.2	19.8	19.3	18.9	18.5	18.0

19 19 18

1	1.0	1.0	1.0	1.0	1.0	1.0
2	3.0	3.0	3.0	3.0	3.0	3.0
3	5.0	5.0	5.0	5.0	5.0	5.0
4	7.0	7.0	7.0	7.0	7.0	7.0
5	9.0	9.0	9.0	9.0	9.0	9.0
6	11.0	11.0	11.0	11.0	11.0	11.0
7	13.0	13.0	13.0	13.0	13.0	13.0
8	15.0	15.0	15.0	15.0	15.0	15.0
9	17.0	17.0	17.0	17.0	17.0	17.0

P. P.

TABLE X.—NATURAL VERSED SINES AND EXTERNAL SECANTS.

60°-70°

70°-80°

°	Vers.	d.	Exsec.	d.	°	Vers.	d.	Exsec.	d.	P. P.
60 0	.5000		1.0000		70 0	.6580		1.9238		
10	.5025	25	1.0101	101	10	.6607	27	1.9473	235	
20	.5050	25	1.0204	102	20	.6634	27	1.9713	240	
30	.5076	25	1.0307	103	30	.6662	27	1.9957	244	
40	.5101	25	1.0413	104	40	.6689	27	2.0205	248	
50	.5126	25	1.0519	105	50	.6717	27	2.0458	253	
61 0	.5152	25	1.0626	106	71 0	.6744	27	2.0715	257	
10	.5177	25	1.0733	107	10	.6772	27	2.0977	262	
20	.5203	25	1.0846	108	20	.6799	27	2.1244	267	
30	.5228	25	1.0957	109	30	.6827	27	2.1513	270	
40	.5254	25	1.1076	110	40	.6854	27	2.1792	276	
50	.5279	25	1.1184	111	50	.6882	27	2.2073	281	
62 0	.5305	25	1.1306	112	72 0	.6910	28	2.2366	287	
10	.5331	25	1.1418	113	10	.6937	27	2.2653	292	
20	.5356	25	1.1536	114	20	.6965	27	2.2951	298	
30	.5382	25	1.1657	115	30	.6993	27	2.3255	304	
40	.5408	25	1.1778	116	40	.7020	27	2.3565	310	
50	.5434	25	1.1902	117	50	.7048	27	2.3881	316	
63 0	.5460	25	1.2027	118	73 0	.7076	28	2.4203	322	
10	.5486	25	1.2153	119	10	.7104	27	2.4531	328	
20	.5512	25	1.2281	120	20	.7132	27	2.4867	335	
30	.5538	25	1.2411	121	30	.7160	27	2.5209	342	
40	.5564	25	1.2543	122	40	.7187	27	2.5558	349	
50	.5590	25	1.2676	123	50	.7215	27	2.5915	356	
64 0	.5616	25	1.2811	124	74 0	.7243	28	2.6279	364	
10	.5642	25	1.2948	125	10	.7271	27	2.6651	372	
20	.5668	25	1.3087	126	20	.7299	27	2.7031	380	
30	.5695	25	1.3228	127	30	.7327	27	2.7420	388	
40	.5721	25	1.3371	128	40	.7355	27	2.7816	396	
50	.5747	25	1.3515	129	50	.7383	27	2.8222	406	
65 0	.5774	25	1.3662	130	75 0	.7412	28	2.8637	414	
10	.5800	25	1.3810	131	10	.7440	27	2.9061	424	
20	.5826	25	1.3961	132	20	.7468	27	2.9495	434	
30	.5853	25	1.4114	133	30	.7496	27	2.9939	444	
40	.5879	25	1.4269	134	40	.7524	27	3.0394	454	
50	.5906	25	1.4426	135	50	.7552	27	3.0859	465	
66 0	.5932	25	1.4586	136	76 0	.7581	28	3.1335	476	
10	.5959	25	1.4747	137	10	.7609	27	3.1824	488	
20	.5986	25	1.4912	138	20	.7637	27	3.2324	500	
30	.6012	25	1.5078	139	30	.7665	27	3.2836	512	
40	.6039	25	1.5247	140	40	.7694	27	3.3362	525	
50	.6066	25	1.5419	141	50	.7722	27	3.3901	539	
67 0	.6092	25	1.5593	142	77 0	.7750	28	3.4454	553	
10	.6119	25	1.5770	143	10	.7779	27	3.5021	567	
20	.6146	25	1.5949	144	20	.7807	27	3.5604	582	
30	.6173	25	1.6131	145	30	.7835	27	3.6202	598	
40	.6200	25	1.6316	146	40	.7864	27	3.6816	614	
50	.6227	25	1.6504	147	50	.7892	27	3.7448	631	
68 0	.6254	25	1.6694	148	78 0	.7921	28	3.8097	649	
10	.6281	25	1.6888	149	10	.7949	27	3.8765	667	
20	.6308	25	1.7085	150	20	.7978	27	3.9451	686	
30	.6335	25	1.7285	151	30	.8006	27	4.0158	707	
40	.6362	25	1.7488	152	40	.8035	27	4.0886	728	
50	.6389	25	1.7694	153	50	.8063	27	4.1636	749	
69 0	.6416	25	1.7904	154	79 0	.8092	28	4.2408	772	
10	.6443	25	1.8117	155	10	.8120	27	4.3205	796	
20	.6470	25	1.8334	156	20	.8149	27	4.4026	821	
30	.6498	25	1.8554	157	30	.8177	27	4.4874	847	
40	.6525	25	1.8778	158	40	.8206	27	4.5749	875	
50	.6552	25	1.9006	159	50	.8235	27	4.6653	904	
70 0	.6580	25	1.9238	160	80 0	.8263	28	4.7582	934	
	Vers.	d.	Exsec.	d.		Vers.	d.	Exsec.	d.	P. P.

9 8 7 6 5 4

50.5 0.4
1.0 0.8
1.5 1.2
2.0 1.6
2.5 2.0
3.0 2.4
3.5 2.8
4.0 3.2
4.5 3.6

3 2 1 0 8 7

0.2 0.1 0.5 0.8 0.7
0.4 0.2 1.0 1.7 1.5
0.6 0.3 1.8 2.5 2.3
0.8 0.4 2.8 3.4 3.0
1.0 0.5 4.7 4.8 3.7
1.2 0.6 5.7 5.1 4.5
1.4 0.7 6.6 5.6 5.2
1.6 0.8 7.6 6.8 6.0
1.8 0.9 8.5 7.6 6.7

6 5 4 3 2 1

29 28 28 27

27 26 26 25

TABLE X.—NATURAL VERSED SINES AND EXTERNAL SECANTS.

80°-85°

85°-90°

°	'	Vers.	d.	Exsec.	d.	°	'	Vers.	d.	Exsec.	d.	P. P.
80	0	.8263	28	4.7587	966	85	0	.9128	29	10.4737		
10		.8292	29	4.8554	999	10		.9157	29	10.8683	.3946	
20		.8321	28	4.9553	1035	20		.9186	29	11.2912	.4229	
30		.8349	28	5.0588	1072	30		.9215	29	11.7455	.4542	
40		.8378	29	5.1660	1111	40		.9244	29	12.2347	.4892	
50		.8407	28	5.2772	1152	50		.9273	29	12.7631	.5284	
81	0	.8435	29	5.3924	1196	86	0	.9302	29	13.3356	.5725	
10		.8464	28	5.5121	1242	10		.9331	29	13.9579	.6223	
20		.8493	29	5.6363	1291	20		.9360	29	14.6368	.6789	
30		.8522	28	5.7654	1343	30		.9389	29	15.3804	.7436	
40		.8550	29	5.8998	1398	40		.9418	29	16.1984	.8186	
50		.8579	29		1456	50		.9447	29	17.1026	.9041	
82	0	.8608	28		1519	87	0	.9476	29	18.1073	1.0047	
10		.8637	29		1585	10		.9505	29	19.2303	1.1230	
20		.8666	28		1656	20		.9534	29	20.4937	1.2634	
30		.8694	29	6.6613	1731	30		.9564	29	21.9256	1.4319	
40		.8723	29	6.8344	1812	40		.9593	29	23.5621	1.6365	
50		.8752	29	7.0156	1898	50		.9622	29	25.4505	1.8884	
88	0	.8781	28	7.2055	1991	88	0	.9651	29	27.6537	2.2032	
10		.8810	29	7.4046	2091	10		.9680	29	30.2576	2.6039	
20		.8839	29	7.6138	2198	20		.9709	29	33.3823	3.1247	
30		.8868	29	7.8336	2315	30		.9738	29	37.2015	3.8192	
40		.8897	29	8.0651	2440	40		.9767	29	41.9757	4.7741	
50		.8926	28	8.3091	2576	50		.9796	29	48.1140	6.1383	
84	0	.8954	29	8.5667	2723	89	0	.9825	29	56.2987	8.1846	
10		.8983	29	8.8391	2884	10		.9854	29	67.7573		
20		.9012	29	9.1275	3059	20		.9883	29	84.9456		
30		.9041	29	9.4334	3250	30		.9912	29	113.5930		
40		.9070	29	9.7585	3460	40		.9942	29	170.8883		
50		.9099	29	10.1045	3691	50		.9971	29	342.7752		
85	0	.9128	29	10.4737		90	0	1.0000		∞		
°	'	Vers.	d.	Exsec.	d.	°	'	Vers.	d.	Exsec.	d.	

	28	29	28
1	2.8	2.9	2.8
2	5.9	5.8	5.7
3	8.8	8.7	8.5
4	11.8	11.6	11.4
5	14.7	14.5	14.2
6	17.7	17.4	17.1
7	20.6	20.3	19.9
8	23.6	23.2	22.8
9	26.5	26.1	25.6

TABLE XI.—USEFUL TRIGONOMETRICAL FORMULÆ.

1	$\sin a = \frac{1}{\operatorname{cosec} a} = \frac{\tan a}{\sqrt{1 + \tan^2 a}} = \sqrt{\frac{1 - \cos 2a}{2}} = \frac{1}{\sqrt{1 + \cot^2 a}}$ $= \cos a \tan a = \sqrt{1 - \cos^2 a} = 2 \sin \frac{1}{2}a \cos \frac{1}{2}a$ $= \frac{1 + \cos a}{\cot \frac{1}{2}a} = \frac{2 \tan \frac{1}{2}a}{1 + \tan^2 \frac{1}{2}a} = \operatorname{vers} a \cot \frac{1}{2}a.$
2	$\cos a = \frac{1}{\sec a} = \frac{\cot a}{\sqrt{1 + \cot^2 a}} = \frac{1}{\sqrt{1 + \tan^2 a}}$ $= 1 - \operatorname{vers} a = \sin a \cot a = \sqrt{1 - \sin^2 a} = 2 \cos^2 \frac{1}{2}a - 1$ $= \sin a \cot \frac{1}{2}a - 1 = \cos^2 \frac{1}{2}a - \sin^2 \frac{1}{2}a = 1 - 2 \sin^2 \frac{1}{2}a.$
3	$\tan a = \frac{1}{\cot a} = \frac{\sin a}{\cos a} = \frac{\sec a}{\operatorname{cosec} a} = \frac{1}{\sqrt{\operatorname{cosec}^2 a - 1}}$ $= \operatorname{vers} 2a \operatorname{cosec} 2a = \cot a - 2 \cot 2a = \sin a \sec a$ $= \frac{\sin 2a}{1 + \cos 2a} = \operatorname{exsec} a \cot \frac{1}{2}a = \operatorname{exsec} 2a \cot 2a.$
4	$\cot a = \frac{1}{\tan a} = \frac{\cos a}{\sin a} = \frac{\sin 2a}{1 - \cos 2a} = \frac{1 + \cos 2a}{\sin 2a}$ $= \sqrt{\operatorname{cosec}^2 a - 1} = \cot \frac{1}{2}a - \operatorname{cosec} a.$
5	$\operatorname{vers} a = 1 - \cos a = \sin a \tan \frac{1}{2}a = 2 \sin^2 \frac{1}{2}a = \cos a \operatorname{exsec} a.$
6	$\operatorname{exsec} a = \sec a - 1 = \tan a \tan \frac{1}{2}a = \operatorname{vers} a \sec a.$
7	$\sin \frac{1}{2}a = \sqrt{\frac{\operatorname{vers} a}{2}} = \frac{\sin a}{2 \cos \frac{1}{2}a} = \frac{\operatorname{vers} a \cos \frac{1}{2}a}{\sin a}.$
8	$\cos \frac{1}{2}a = \sqrt{\frac{1 + \cos a}{2}} = \frac{\sin a}{2 \sin \frac{1}{2}a} = \frac{\sin a \sin \frac{1}{2}a}{\operatorname{vers} a}.$
9	$\tan \frac{1}{2}a = \operatorname{vers} a \operatorname{cosec} a = \operatorname{cosec} a - \cot a = \frac{\tan a}{1 + \sec a}.$
10	$\cot \frac{1}{2}a = \frac{1 + \cos a}{\sin a} = \operatorname{cosec} a + \cot a = \frac{\tan a}{\operatorname{exsec} a} = \frac{1}{\operatorname{cosec} a - \cot a}.$
11	$\operatorname{vers} \frac{1}{2}a = 1 - \sqrt{\frac{1}{2}(1 + \cos a)}.$
12	$\operatorname{exsec} \frac{1}{2}a = \frac{1}{\sqrt{\frac{1}{2}(1 + \cos a)}} - 1.$

TABLE XI.—USEFUL TRIGONOMETRICAL FORMULÆ.

$$13 \quad \sin 2a = 2 \sin a \cos a = \frac{2 \tan a}{1 + \tan^2 a}.$$

$$14 \quad \cos 2a = \cos^2 a - \sin^2 a = 1 - 2 \sin^2 a = 2 \cos^2 a - 1 \\ = \frac{1 - \tan^2 a}{1 + \tan^2 a}.$$

$$15 \quad \tan 2a = \frac{2 \tan a}{1 - \tan^2 a}.$$

$$16 \quad \cot 2a = \frac{1}{2} \cot a - \frac{1}{2} \tan a = \frac{\cot^2 a - 1}{2 \cot a} = \frac{1 - \tan^2 a}{2 \tan a}.$$

$$17 \quad \text{vers } 2a = 2 \sin^2 a = 1 - \cos 2a = 2 \sin a \cos a \tan a.$$

$$18 \quad \text{exsec } 2a = \frac{\tan 2a}{\cot a} = \frac{2 \tan^2 a}{1 - \tan^2 a} = \frac{2 \sin^2 a}{1 - 2 \sin^2 a}.$$

$$19 \quad \sin (a \pm b) = \sin a \cos b \pm \cos a \sin b.$$

$$20 \quad \cos (a \pm b) = \cos a \cos b \mp \sin a \sin b.$$

$$21 \quad \sin a + \sin b = 2 \sin \frac{1}{2}(a + b) \cos \frac{1}{2}(a - b).$$

$$22 \quad \sin a - \sin b = 2 \sin \frac{1}{2}(a - b) \cos \frac{1}{2}(a + b).$$

$$23 \quad \cos a + \cos b = 2 \cos \frac{1}{2}(a + b) \cos \frac{1}{2}(a - b).$$

$$24 \quad \cos a - \cos b = -2 \sin \frac{1}{2}(a + b) \sin \frac{1}{2}(a - b).$$

Call the sides of any triangle A, B, C , and the opposite angles a, b , and c . Call $s = \frac{1}{2}(A + B + C)$.

$$25 \quad \tan \frac{1}{2}(a - b) = \frac{A - B}{A + B} \tan \frac{1}{2}(a + b) = \frac{A - B}{A + B} \cot \frac{1}{2}c.$$

$$26 \quad C = (A + B) \frac{\cos \frac{1}{2}(a + b)}{\cos \frac{1}{2}(a - b)} = (A - B) \frac{\sin \frac{1}{2}(a + b)}{\sin \frac{1}{2}(a - b)}.$$

$$27 \quad \sin \frac{1}{2}a = \sqrt{\frac{(s - B)(s - C)}{BC}}.$$

$$28 \quad \cos \frac{1}{2}a = \sqrt{\frac{s(s - A)}{BC}}.$$

$$29 \quad \text{vers } A = \frac{2(s - B)(s - C)}{BC}.$$

$$30 \quad \text{Area} = \sqrt{s(s - A)(s - B)(s - C)} = A^2 \frac{\sin b \sin c}{2 \sin a}.$$

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